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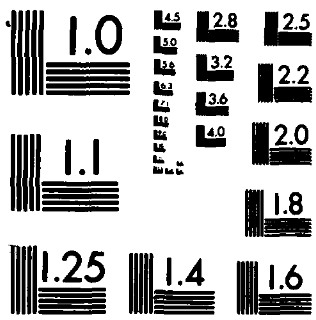

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AN EVALUATION OF SARP DRIFT PREDICTIONS USING SATELLITE-TRACKED DRIFT-BUOYS

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Interim Report

December 1982

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WASHINGTON D.C. 20590

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Technical Report Documentation Page

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This report is the fourteenth in a series which documents the Probability of Detection in Search and Rescue (POD/SAR) Project at the USCG R&D Center. It is the second report to deal with the drift task of the project.

16. Abstract

During the period of 1979 through 1981 the USCG Research and Development Center conducted several experiments in which the drift predictions of the computerized Search and Rescue Planning System (SARP) were compared with the movement of satellite-tracked drift-buoys released in the Gulf Stream east of Florida. Buoy positions at specific times were used as the last known position and incident date-time-group of a simulated search and rescue (SAR) incident; subsequent buoy positions were used to test the accuracy of 24, 48, 72, 96, and 120 hour drift predictions.

Of the 680 drift predictions evaluated, in only 41 cases (6.0%) was the interpolated buoy position within the SARP-predicted search area.

A statistical analysis of the major experimental variables (wind type, prediction time, and sea current file) showed that:

1. The accuracy of the drift predictions degraded with increasing prediction time,
2. There was no discernible difference between the predicted (forecast) and analysis (observed) wind results,
3. If the effect of wind is not included in the drift prediction the result is a larger relative drift error,
4. The sea current files used in the SARP drift predictions contain some systematic errors which adversely affect system performance, and
5. The drift error factor presently in use seriously underestimates the total drift error.

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METRIC CONVERSION FACTORS

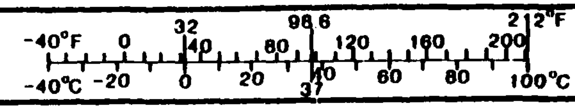
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25, SD Catalog No. C13.10.286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



Acknowledgements

The assistance of many individuals and organizations made this research possible. The personnel of Commander, Atlantic Area (Aso) and the former Oceanographic Unit deserve particular recognition for their efforts. In addition, the crews of USCGC EVERGREEN, VIGOROUS and DECISIVE assisted substantially in the deployment and recovery of the drift-buoys. The assistance of Dr. G. McNally of Scripps Institute of Oceanography is also appreciated.

Appreciation is extended to CDR N. C. EDWARDS who initiated this research while stationed at USCG Research and Development Center. Finally, the assistance of E. L. PRESHER III, D. GOOD, M. EVERSON, and R. W. FORTIN is gratefully acknowledged.

EXECUTIVE SUMMARY

INTRODUCTION

This report addresses the accuracy of the USCG methods of predicting the drift of search targets. During the period of 1979 through 1981, the USCG Research and Development Center (R&DC) conducted several experiments in which the drift predictions of the computerized Search and Rescue Planning System (SARP) were compared with the movement of 12 satellite-tracked drift-buoys released in the Gulf Stream off the east coast of Florida. Buoy positions at specific times were used as the last known position (LKP) and incident date-time-group of a simulated search and rescue (SAR) incident. The SARP predictions, calculated by the Operations Analysis Branch of Commander, Atlantic Area (Aso), at Governors Island, New York, were then compared with the subsequent buoy motions to test the accuracy of the SARP drift predictions.

The major experimental variables were:

1. Wind. Emphasis was placed on the role of wind-driven current in the SARP drift predictions, particularly the sensitivity of the predictions to the type of wind input. For most of the simulated SAR incidents three different SARP cases, using different wind inputs, were run. They were:

a. Analysis winds - These are winds based on observations and represent the best wind data available to SARP.

b. Predicted winds - Typical of the winds used for actual SAR incidents, this case is actually a combination of analysis and forecast winds.

c. No wind - A control case run using no wind input, therefore, the drift is due solely to the sea current.

During the experiments, the leeway of the search targets (buoys) was assumed to be zero; therefore, wind affects the SARP prediction only as a driving mechanism for the surface current.

2. Length of prediction. Although the largest number of experimental SARP runs were made for a 24-hour drift interval, longer drift intervals (48, 72, 96, and 120 hours) were also run to test the performance of the drift predictions at longer intervals.

3. Sea current files. The performance of the SARP drift predictions was analyzed to determine the influence of the sea current files on the system accuracy. The results of predictions made using three files (FLDA, NAVO, and CORE) were examined in detail. Two of these, FLDA and NAVO, are used in the recently implemented Computer Assisted SAR Planning (CASP) system.

RESULTS

o SARP drift predictions. The search target was within the SARP-predicted search area in 6% (41) of the 680 drift predictions evaluated. When only the 24-hour interval is considered, the success increases slightly to 9.1%. For intervals longer than 24 hours the success was 1.5%.

o <u>Wind</u>. There was no difference between the results of the analysis and predicted wind cases. SARP performance is affected by whether or not wind is included in the computations and the no wind case leads a larger relative drift error than either the analysis or predicted wind cases.

o <u>Length of Predictions.</u> The performance of the SARP drift predictions degrades with increasing prediction time.

o <u>Current files.</u> The sea current files used in the SARP drift predictions contain systematic errors which adversely affect the system performance. NAVO consistently underestimates the actual net drift while both FLDA and CORE overestimate the drift. Both FLDA and CORE have bearing errors which result in a predicted net target drift to the west of the actual movement.

o <u>Drift error factor.</u> The presently used value (1/8) of the drift error factor, which is used to estimate the error in the total drift, is an unreasonably low estimate. The value (0.3) given in the recent amendment to Chapter 8 of the National Search and Rescue Manual is an improvement but still underestimates the drift error associated with the present sea current files. The actual drift error, based on the experimental data, is approximately 1.0, which means that the drift error is nearly equal to the total predicted drift.

CONCLUSIONS

o The sea current files used by SARP in the study area contain inaccuracies which lead to serious errors in predicted search target drift.

o Despite the fact that NAVO consistently underestimates the net target drift, it is an effective file because 75% of the time the actual target location was closer to the datum than to the LKP.

o CORE is also judged to be effective (although marginally) despite the observed errors. In 60% of the cases examined, the target was closer to datum than the LKP.

o FLDA is an ineffective sea current file; in 75% of the cases tested the target was closer to the LKP.

o The drift error factor used by SARP seriously underestimates the total drift error associated with the present sea current files.

o Because the recently implemented CASP system relies on two of the three sea current files examined in this study (NAVO and FLDA), the results of a similar study using CASP would probably lead to similar results.

SUGGESTIONS

The following are several suggestions for future work leading to improvements in SAR drift predictions.

o Rerun the CORE area SARP evaluations using CASP (with the NAVO file) to determine whether the results are significantly different.

- If necessary, modify CASP to accept the GULF file (which includes CORE) and re-institute the analysis of satellite IR data to support the GULF file.

- Investigate the feasibility of making FLDA a non-static file to allow, at a minimum, a seasonal cycle.

- Develop a real-time data collection technique for use during search to update the sea current files to reflect on-scene conditions.

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1.0 INTRODUCTION

1.1 Background

Predicting the drift of a search object on the sea surface has long been recognized by the U.S. Coast Guard (USCG) to be an important part of effective search planning. The difficulty of making such predictions is equally clear. The forces which cause movement of a distressed vessel or person away from the original position of distress are many and complex; wind drag on the object (leeway), sea currents and local wind-driven currents are but a few.

This report addresses the accuracy of the USCG methods of predicting the drift of search targets. During the period of 1979 through 1981, the USCG Research and Development Center (R&DC) conducted several experiments in which the drift predictions of the computerized Search and Rescue Planning System (SARP) were compared with the movement of 12 satellite-tracked drift-buoys released in the Gulf Stream off the east coast of Florida (Figure 1-1). Buoy positions at specific times were used as the last known position (LKP) and incident date-time-group (DTG) of a simulated search and rescue (SAR) incident. The SARP predictions, calculated by the Operations Analysis Branch of Commander, Atlantic Area (Aso), at Governors Island, New York, were then compared with the subsequent buoy motions to test the accuracy of the SARP drift predictions.

The Gulf Stream was chosen as the study site for several reasons. It is an area which has been the subject of considerable oceanographic study (see Stommel, 1972 and Richardson, 1980, for example) and as a result there are a great deal of historical oceanographic data available for the region. In addition, the region is constantly being monitored using satellite imagery. Summaries of the distribution of water masses are prepared weekly by the National Environmental Satellite Service (NESS, 1980-1981) of the National Weather Service (NWS) and the U.S. Naval Eastern Oceanography Center (NAVEASTOCEANCEN, 1979-1982). In addition, monthly summaries of the major Gulf Stream features are published in GULFSTREAM (NOAA, NWS, 1979-1980) and, more recently, in the Oceanographic Monthly Summary (NOAA, NWS, 1981). All of these summaries were useful in analyzing the buoy motions.

The region presents a severe test for the SARP drift predictions, particularly for the accuracy of the sea current files. At first glance it might seem that, because the Gulf Stream dominates the flow in the region and much is known about its mean characteristics, predicting the movement of an object released in the Stream should not be exceedingly difficult. However, the flow is actually quite complex. For example, a recent NAVEASTOCEANCEN frontal analysis (Figure 1-2) shows that the Gulf Stream is characterized by complex geometry, with wave-like features along the west wall and cold core eddies (CE) at the eastern boundary. In addition, there are two CEs detached from and to the east of the Gulf Stream.

A final advantage of the chosen study area is that in a large portion of the area two of the major sea current files used in SARP, the FLDA and GULF files overlap. The files and their boundaries will be discussed in detail later.

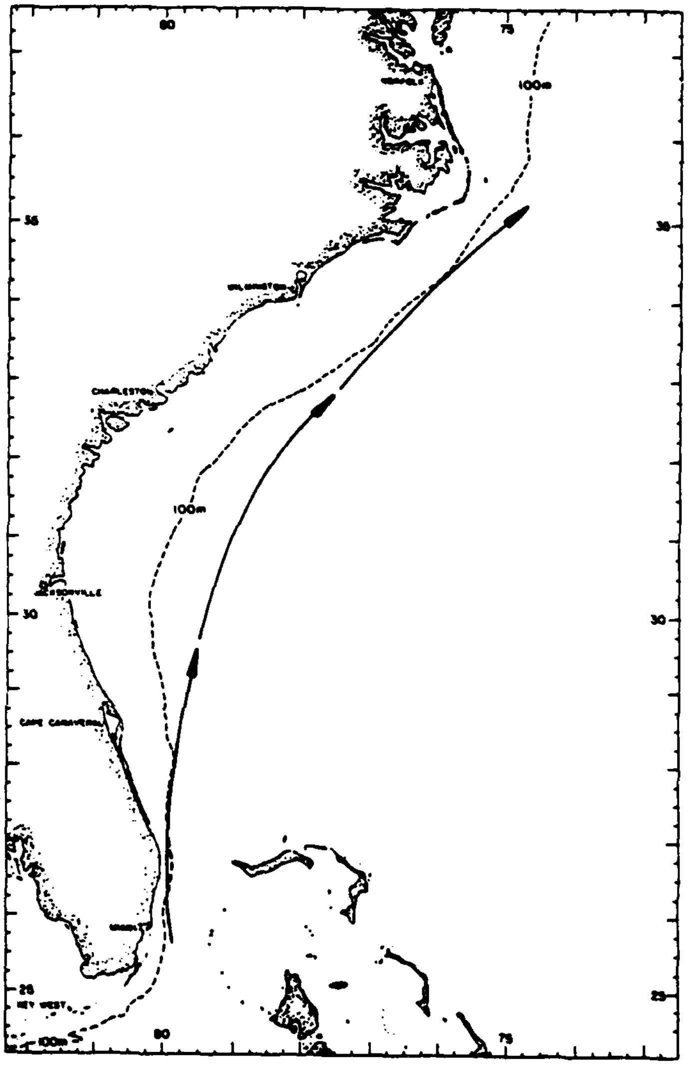


FIGURE 1-1. AREA OF STUDY. The arrows indicate the approximate historical position of the maximum current for the month of March (GULFSTREAM, Vol IV(2), February 1978).

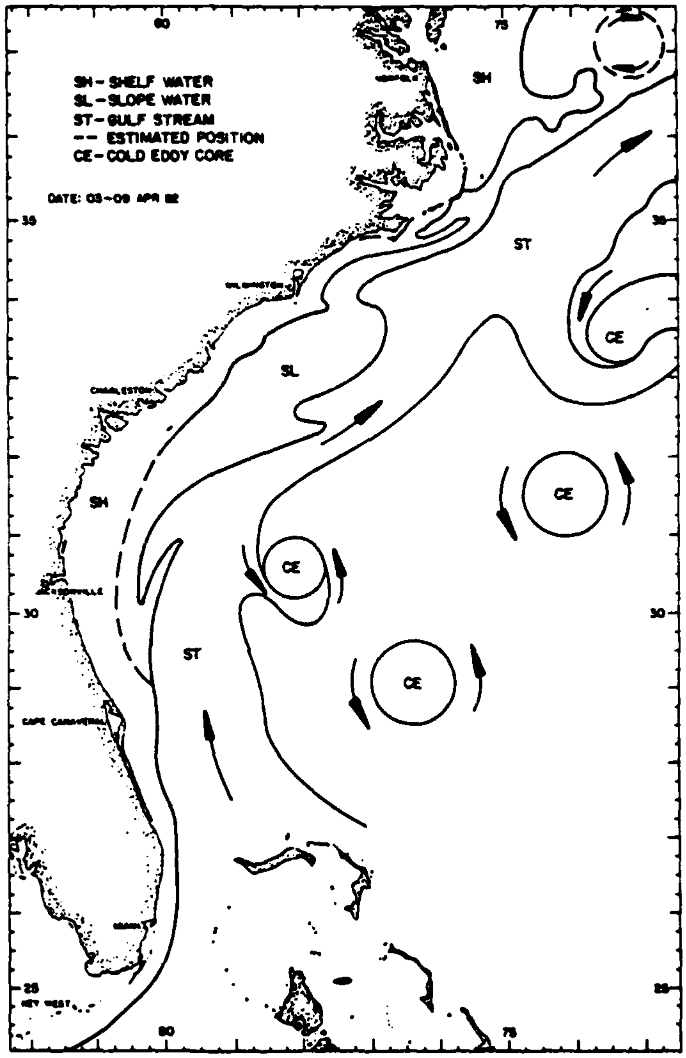


FIGURE 1-2. Ocean Frontal Analysis for 3-9 April 1982 provided by U.S. Naval Eastern Oceanography Center (NAVEASTOCEANCEN), Norfolk, VA.

While the three-year experiment was being conducted, SARP was the operational system at Atlantic Area; however, a more sophisticated method of search planning, the Computer Assisted Search Planning (CASP) system, has replaced SARP (Summer 1982). The results of the evaluation of SARP predictions are useful for several reasons. First, the data files (wind and current) used by CASP are essentially the same as those used by SARP and are the primary factors in the accuracy of the drift predictions. For example, in the area of study CASP uses two out of the three sea current files employed by SARP; these current files will be explained in detail later. Second, SARP provides a more direct evaluation of the drift problem because it provides a datum rather than the probability cell format of CASP. Finally, the SARP system remains available for use throughout the Coast Guard as a search planning guide; indeed, First District (CCGDONE) personnel have developed and are testing a local SARP system designed to run on a minicomputer at the district operations center in Boston (Whitehurst, 1982).

1.2 Report Outline

This report begins with a brief description of the SARP system (2.0) in which those factors which bear directly on the drift problem are presented. Particular emphasis is placed on the data files used in the drift predictions and the major assumptions of the study. Next follows a description of the methods of data acquisition (3.0). In this chapter the satellite-tracked drift-buoys, the buoy positioning systems, and details of the SARP drift predictions are presented. In addition, the buoy tracks for the period of the SARP drift evaluation are presented and these data are compared with available satellite imagery in an attempt to identify any major oceanographic features in the study area.

Chapter 4 presents a description of the data analysis and the major results of the study. The analysis proceeds on two levels. The first is a direct comparison of interpolated buoy positions with the limits of the SARP-determined search area to determine whether or not the search object was within the area. The second is a statistical analysis in which the accuracy of the SARP drift prediction is evaluated according to several performance criteria. The role of the major experimental variables, namely wind, length of prediction, and sea current file, is examined. The chapter ends with a discussion of the accuracy of the drift error factor. In the final chapter (5.0) the conclusions of the study and suggestions for future work are presented.

To be consistent with the National Search and Rescue Manual (henceforth SAR Manual) and SARP, the nautical system of units (knots, etc.) is employed in this report; metric conversions are provided where appropriate. Julian dates (JD) are provided where appropriate because this calendar system, in which the days of the year are numbered sequentially starting 1 January, is convenient when dealing with drift intervals spanning several months.

2.0 SEARCH AND RESCUE PLANNING SYSTEM (SARP)

2.1 Introduction

The discussion of SARP presented here is focused on those aspects which bear directly on the drift study. A more complete description of SARP can be gained from the Computerized Search and Rescue Handbook (1974) and the SAR Manual. In the course of the SARP description, the assumptions used in the evaluation are discussed; they are summarized at the end of the chapter.

2.2 System Description

SARP consists of a series of computer programs and data files which are used to assist in search planning. It is particularly useful in relatively straightforward incidents in which there is little uncertainty in the time and the place of the distress case, and in which the environmental conditions are stable.

SARP is designed so that only four inputs are required for a run. They are:

a. incident date-time-group (DTG),
b. last known position (LKP),
c. position error of the distress craft, and
d. position error of the search craft.

For the SARP drift evaluation experiment, the incident DTG and last known position (LKP) were taken from the buoy position data. The position error of the distress craft and search craft were assumed to be equal to the approximate position error of the buoy tracking system (3 nautical miles); a detailed discussion of the satellite tracking system and error estimates is presented in 3.2.1.

In addition to the four required inputs, SARP is designed to accept several optional inputs which enhance the flexibility of the system; the optional inputs relevant to the present investigation are presented below.

a. Local wind current. There is a computer routine, based on curves developed by James (1966), in SARP which calculates the magnitude of the surface current generated by the local wind. The curves, which are presented as a function of wind duration and fetch, are based on observations of the drift of surface-borne objects of many types gathered from a variety of investigations. In the fully developed case, the curves were made to fit the drift data, and the surface wind currents were in the range of 2.0% to 2.8% of the surface wind speed.

Because of the Coriolis effect, the direction of the wind-driven currents is assumed to be deflected to the right of the local surface wind (in the northern hemisphere) as a function of latitude. The deflection varies from 0° at the equator to 30° at latitudes greater than 60°; for the area of the present study the deflection angle is 20°.

A proposed change to the SAR Manual, presently being reviewed, replaces the curves developed by James (1966) with a method to calculate locally generated wind current developed by Mooney (1978) of the USCG Oceanographic Unit (CGOCEANO). This method is an application of a solution (Jelesnianski, 1970) to time-dependent Ekman dynamics. The method is considerably more sophisticated than the James curves; the required computations are explained in detail in the proposed change to Chapter 8 of the SAR Manual.

b. Leeway. Leeway describes the movement of an object through the water due to the wind stress on that portion of the object projecting above the sea surface, i.e., the sail area. This motion is distinct from the effect of the wind on the surface current and is calculated separately in SARP. The leeway speed is a function of the type of craft; equations representing this mechanism are presented in the SAR Manual and are used in the SARP calculations.

In the present study leeway is assumed to be zero; the justification for this assumption is presented in Section 3.2.1. Because of the zero leeway assumption, the only wind effect that this report addresses is the target movement due to wind-driven surface currents.

c. Surface winds. The SARP program can either accept surface wind information provided by an on-scene unit or access wind files based on data provided by the U.S. Navy Fleet Numerical Oceanography Center (FNOC) in Monterey, California. The data files contain both predicted (forecast) and analysis (historical) surface winds for a relatively coarse ($5^{\circ} \times 5^{\circ}$) grid which covers the region of 25°W to 140°E and 15°N to 70°N. They are updated twice daily and the predicted winds are replaced by analysis winds in the updating process. The analysis winds are kept on file for a period of 90 days.

For a SARP prediction, wind data are required for a period of 48 hours prior to the commencement of the target drift up until the time of the predicted datum. In an actual SAR case, the winds are usually a combination of analysis and predicted winds. When any predicted winds are utilized in a SARP prediction, a warning is displayed on the SARP output which states the period (in hours) for which predicted winds were used.

d. Average sea current. The average sea current is defined as the permanent, large-scale flow which is independent of the local wind or tides. SARP can either accept input from on-scene units or access one of the several sea current files which provide regional mean circulation data. Several of the available data files, along with a brief description, are presented below:

(1) NAVO. This file, based on data compiled and analyzed by the U.S. Navy Oceanographic Office, consists of monthly average currents (there are actually 12 files) for the area bounded approximately by 10°S to 70°N latitude and 0°W to 120°E longitude. The data are arranged in a coarse $1^{\circ} \times 1^{\circ}$ grid and are used by both SARP and CASP.

Because the NAVO file (also known as the Wagner file) is based on set and drift data the mean sea currents are contaminated to an unknown extent by local wind current and leeway effects. No attempt has been made to remove these effects; thus, the NAVO data does not strictly meet the average sea current definition presented above.

(2) Florida Straits File. Known as the FLDA file, this data file contains the average current in the region bounded by 24°N and 32.7°N in latitude and 78.2°W and 81.9°W in longitude. The current data file is time invariant and is automatically accessed for SAR cases in the region unless the Gulf Stream override option is specified. When the GULF override is specified the Gulf Stream file takes precedence where the two files overlap. The FLDA file is used by both SARP and CASP although the formats differ somewhat.

(3) Gulf Stream File. Two separate data files, CORE and EDDY, constitute the Gulf Stream file (GULF). As their names imply, CORE describes the surface flow field in the core region of the Gulf Stream, and EDDY describes the nearly circular surface currents in any eddies that might be in the area of file coverage (approximately 27°N-41°N and 67°W-81°W). During the period of the experiment, these files were updated weekly using a process described in USCG Oceanographic Unit (CGOCEANO) Technical Report 78-3. Only SARP uses the Gulf Stream file.

The primary source of the data that go into the GULF file is satellite imagery, both infrared (IR) and visual, provided by NOAA. Other data sources such as temperature profiles provided by FNOC and Airborne Radiation Thermometry (ART) formerly collected by the CGOCEANO were also used. Essentially, the process involves the identification of water masses using the surface temperature distribution. The boundaries of the core and any eddies are identified and an assumed velocity distribution is used to create the data files. The weekly GULF files are retained for a period of two years.

(4) Sea current files for the New York Bight (38°N-41°N and 70.5°W to 75°W), known as NYBI and a tidal file for Long Island Sound (TIDE) are also available for use with the SARP program.

Figures 2-1 and 2-2 (reprinted from the Computerized Search and Rescue Handbook) show the approximate areas covered by the sea current files. In the area of study, SARP utilizes three major sea current files: NAVO, FLDA and GULF; CASP employs NAVO and FLDA. The SARP output lists the specific sea current files used during the drift calculations. In some cases only one file is utilized for an entire drift prediction, while in other cases a combination of two or three files might be employed.

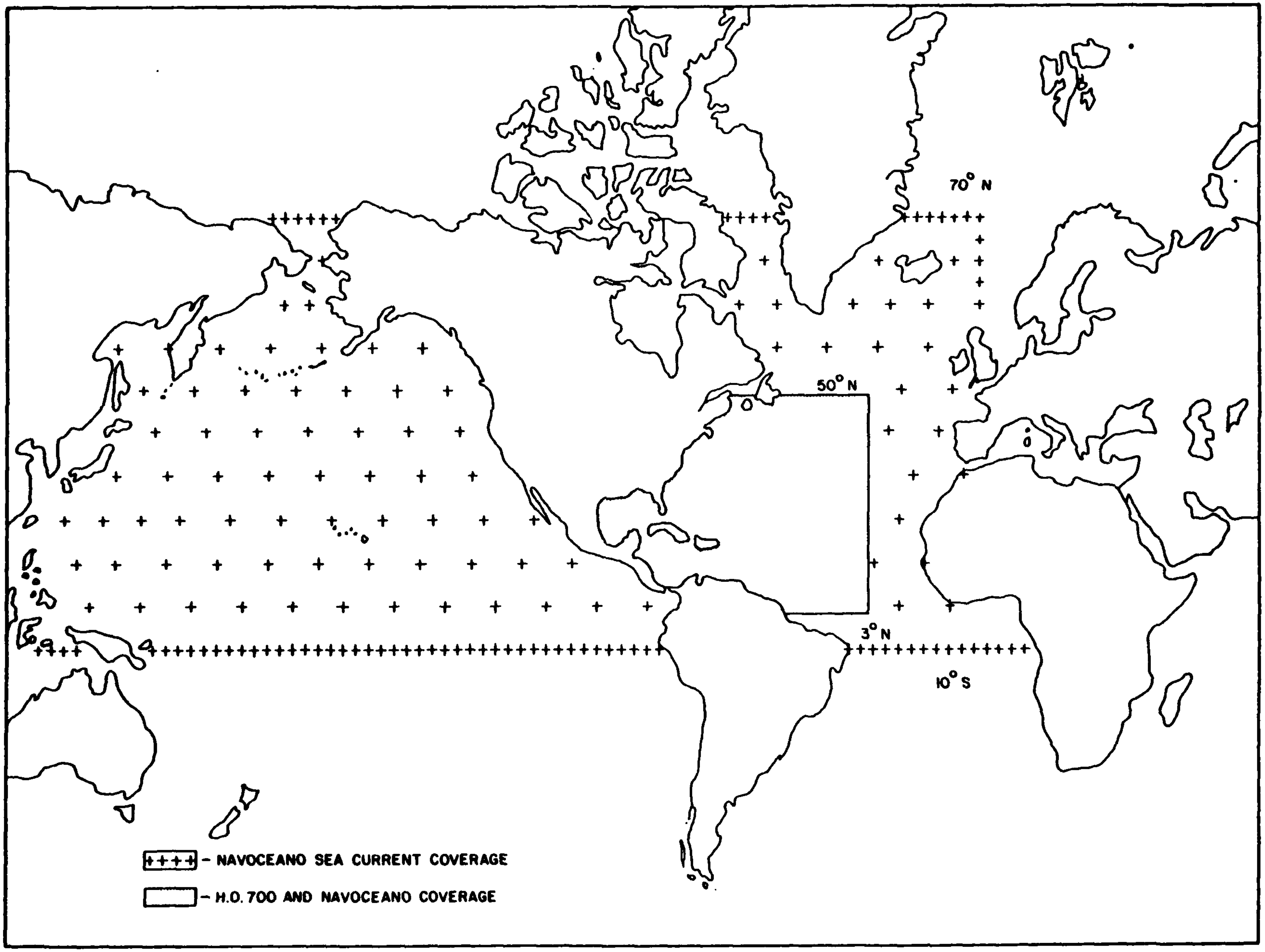


FIGURE 2-1. Boundaries of the Worldwide sea current files used by SARP (USCG Computerized SAR Handbook).

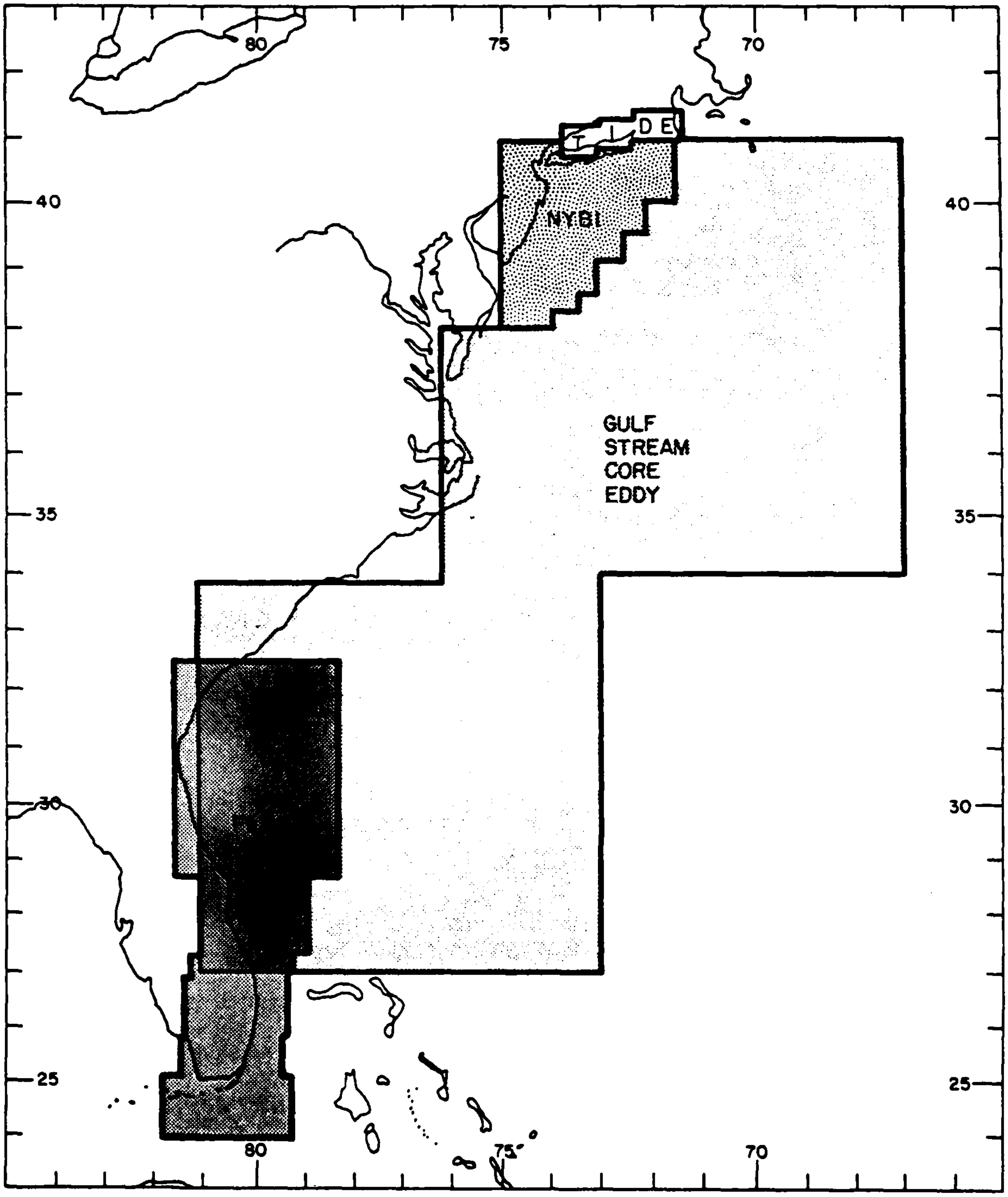


FIGURE 2-2. Boundaries of the Atlantic Ocean SAR Current Files from USCG Computerized SAR Handbook.

The output of the SARP program includes a computed total probable error of position and a datum, which is the probable location of the search object. The total probable error, E (in nmi), is computed using (SAR Manual, p8-27),

$$E = (D_e^2 + X^2 + Y^2)^{1/2} \quad \text{where,} \qquad \text{(Eq. 2-1)}$$

D_e = total drift error (nmi)
X = initial position error (nmi)
Y = search craft position error (nmi).

The expression for the total drift error is

$$D_e = (E_d)(TD) \qquad \text{(Eq. 2-2)}$$

where,

TD = the total predicted drift during the drift interval
E_d = the drift error factor = 1/8.

The initial position error (X) and the search craft error (Y) are estimates of the navigational accuracy of the distressed, and search craft, respectively. For all of the SARP drift predictions evaluated in this report, X and Y were assumed to be 3 nmi (5.6 km). This value was chosen because it is the approximate position error for the NIMBUS Oceanographic Drifters used in the first year's (1979) experiment. The same error estimate was also used in 1980 and 1981 because actual value is not so important so long as it is the kept constant for all of the runs.

The value of E is of critical importance because it is used to calculate the search radius (R) which in turn is used to determine the search area. The values of X and Y are not particularly controversial so long as they are held the same throughout the drift evaluation. The computation of the drift error using a drift error factor (E_d) of 1/8 warrants considerable attention since the implied claim is that the total drift of an object on the sea surface can be estimated to within 12.5%. The origin of 1/8 factor is uncertain. The SAR Manual states that, as a practical matter, this assumption has been "reasonably verified" over numerous years of search planning. The proposed change to the SAR Manual recommends that the 1/8 factor be changed to 0.3, a figure which was obtained from two sources. First, USCG Headquarters staff used drift data from Hufford and Broida (1974), which was collected as part of a leeway drift experiment in a nearshore region. Second, in 1976 USCG Atlantic Area staff analyzed the drift of several actual SAR cases and found that the E_d was 0.3. The 0.3 value seems to be an improvement but, with the present data, the issue of the accuracy of this E_d can be addressed.

As described in the SAR Manual, the first search area is chosen so that there is a 50% chance that the search target is in the area. A circle with the center at the datum and of radius E fits this criterion. To ensure that the probability is greater than 50%, a safety factor (f_s) is used to compute the first search radius. It is

$$R = f_s E \qquad \text{(Eq. 2-3)}$$

where f_s = 1.1 for the first search radius.

Because there are few search patterns which are easily adaptable to a circular search area, a square is circumscribed around the first search circle. Thus a square search area with sides equal to 2R and centered at datum is established (Figure 2-3).

2.3 Summary of SARP Drift Evaluation Assumptions

a. Buoy positions are used for the last known position and the times are the incident DTG of simulated SAR cases.

b. The position error of the distress craft is 3 nmi (5.6 km).

c. The position error of the search craft is 3 nmi (5.6 km).

d. The distressed craft (buoy) has zero leeway.

e. The total drift error (D_e) is the arithmetic sum of all of the individual drift errors (d_e) accumulated during a SARP prediction. The computation of d_e, which is the error for a specified time interval (Δt), assumes that d_e is 1/8 of the total drift (td) during Δt. Thus,

$$d_e = \frac{1}{8}\, td \qquad \text{(Eq.2-4)}$$

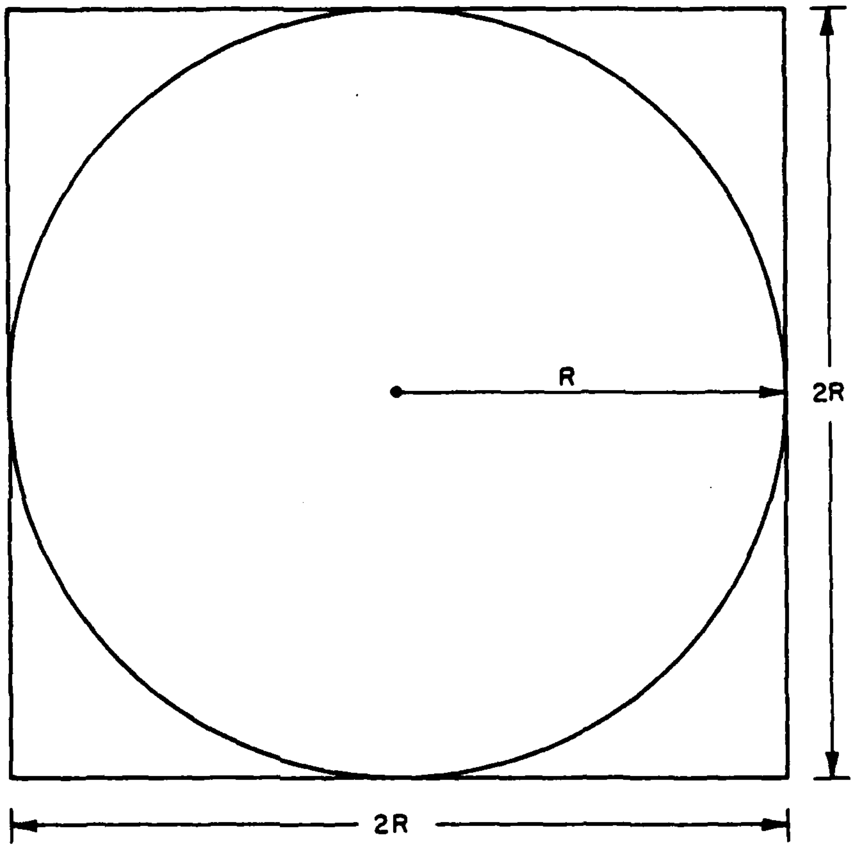


FIGURE 2-3. Construction of a Search Area using the Search Radius, R.

3.0 DATA ACQUISITION

3.1 Introduction

In this chapter the details of data acquisition are presented. First, the drift buoys and two tracking systems used in the experiment are described. Next, the buoy tracks for the periods during which SARP comparisons were made in each of the three years of the study are presented. Finally, the specific SARP cases for each of the three years are presented in detail.

3.2 Buoy Positions

3.2.1 Buoy/Tracking System Description

Two buoy types, tracked by different satellites and with different hull designs, were employed in this study. The buoys, named for the tracking satellites, are the NIMBUS Oceanographic Drifter (NOD) and TIROS Oceanographic Drifter (TOD). The positions of the buoys are determined by a Doppler shift in the carrier frequency of the buoy transmissions during a satellite pass. The NODs were tracked by the Random Access Measurement System (RAMS) on board the NIMBUS 6 satellite; Kirwan et al. (1976) provide a summary of RAMS. The advertised position accuracy of RAMS is $\pm$ 5 km ($\sim$ 3 nmi). This is probably a conservative estimate; for example, Robe et al. (1980) found the position uncertainty to be $\pm$ 3.52 km (1.90 nmi) in the Labrador Sea and Baffin Bay. The TODs are tracked by the ARGOS system on board the TIROS/NOAA series satellites and provide a system accuracy of $\sim$ 300 m (.2 nmi); Bessis (1981) provides a description of the ARGOS system.

Two different buoy hulls were used. The hulls designed by Scripps Institute of Oceanography (SIO) consisted of a 38.1 cm diameter fiberglass cylinder approximately 3 meters long (Figure 3-1). None of the SIO hulls was fitted with a drogue. The hulls designed by Polar Research Laboratory (PRL) of Santa Barbara, California, are approximately the same length as the SIO hull and are shown in Figure 3-2. The PRL hulls were fitted with nylon window shade drogues ($\sim$ 2 meters wide by $\sim$ 11 meters long). The drogues were tethered to the buoy hull by a 1.27 cm (1/2") nylon line which was 30 meters long. A drogue sensor which incorporated a load cell was mounted on the lower end of the buoy hull. This sensor provided a drogue "on/off" indicator with the position data. All NODs had SIO hulls. With the exception of buoy ID #2649, the TODs had PRL hulls. Buoy ID #2649 was a TOD with a SIO hull and was launched in 1980.

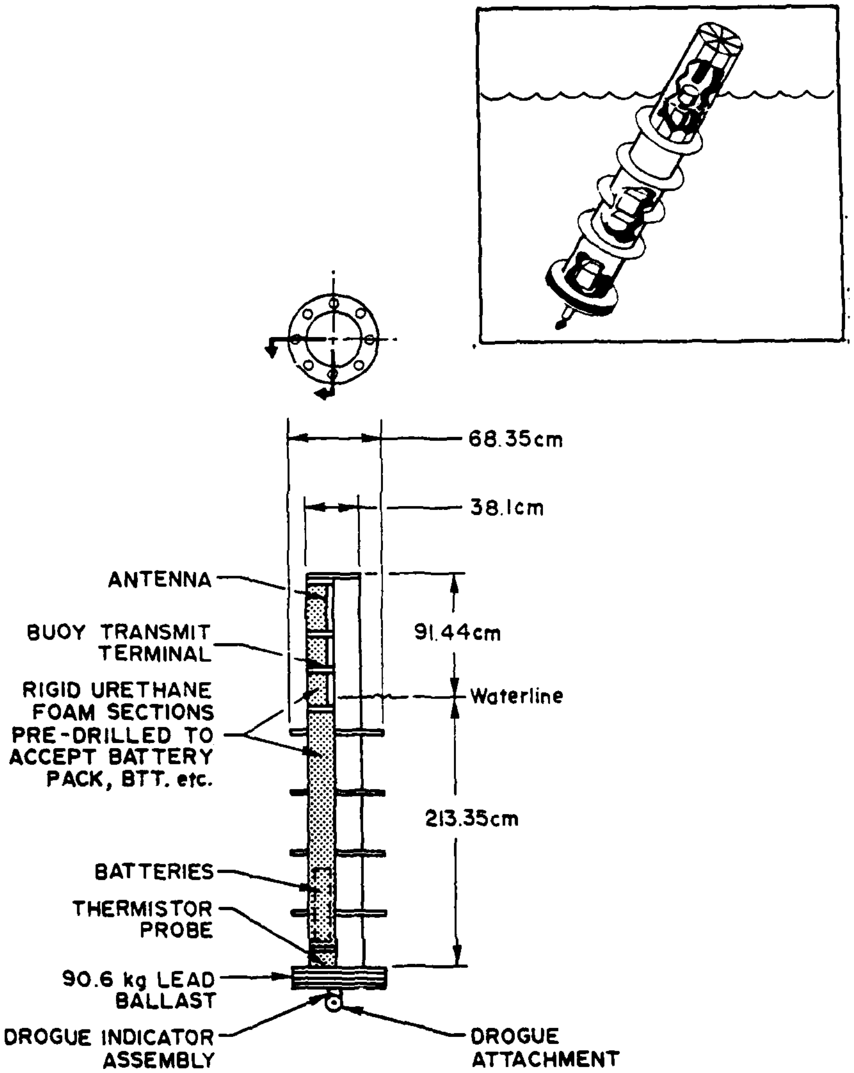


FIGURE 3-1. Scripps Institute of Oceanography (SIO) Hull Design.

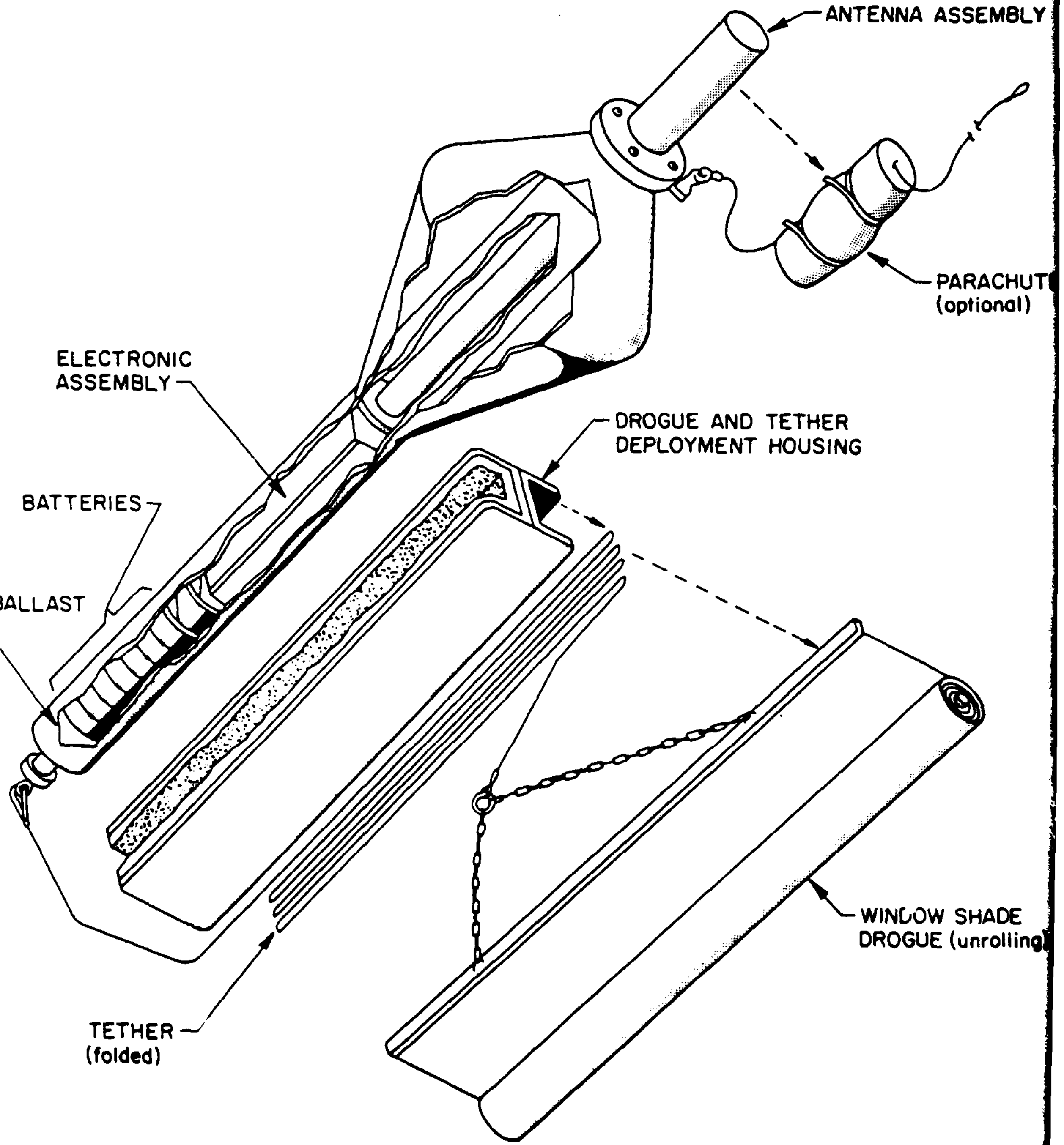


FIGURE 3-2. Polar Research Laboratory (PRL) Hull Design.

In 1979 the buoys were exclusively NODs. In 1980 the buoys providing the drift data were TODs (2649 had a SIO hull). Finally, in 1981 one TOD and one NOD were launched; a summary of the launch data for the three-year experiment is contained in Appendix A.

The assumption that the buoys have zero leeway is made recognizing the fact that, because a portion of the buoys is above the sea surface, there is some wind stress acting directly on the buoy hull. For the buoys fitted with drogues, the leeway is clearly negligible when compared to the movement caused by the near-surface flow field. For the undrogued buoys, the ratio of the submerged area to exposed area was approximately 2:1 for each of the two hull types used. This ratio suggests that movement due to leeway is not a dominant factor. Indeed, a recent study (McNally, 1981) showed that there was no significant systematic difference between the movement without drogues and those drogued at 30 meters.

3.2.2 Buoy Tracks

The buoy releases and the acquisition of the position data are described in this section. It is not the intent to present a detailed analysis of the buoy movement, but to develop an oceanographic framework for discussion of the accuracy of the drift predictions. The primary sources of data were the Gulf Stream analyses derived from satellite imagery. In some cases, the buoy movements could be related to major features shown by the imagery. Each year of the three-year study is considered separately.

a) 1979. Of the 6 undrogued NODs released in the Gulf Stream in 1979, 5 provided positions for the entire 24-day SARP drift evaluation period (29 January-22 February). The release locations (Figure 3-3) are plotted on the Weekly Sea Current Chart which was formerly a regular product of CGOCEANO. This chart, which is an example of the charts used to generate the GULF file (Section 2.2d), was constructed using satellite IR data near the buoy launch date (29 January).

The buoys were launched in an east/west line at 28°N, extending from the approximate location of the western boundary to the assumed position of the Gulf Stream core, indicated by the 4.0 kt (2.1 ms^{-1}) isotach. The buoys were tracked by both CGOCEANO using their local user terminal (LUT) and by the National Aeronautics and Space Administration (NASA); the NASA positions were relayed to R&DC by SIO. Because there was a considerable time lag (1-3 months) in receiving the data from SIO, the CGOCEANO positions were used for the SARP inputs. The NASA-provided positions were used to augment the data files and to evaluate the SARP predictions.

There was an average of one good fix for every 32 hours for each of the 5 platforms; however, there were also data gaps of up to 4 days in some of the records. This was a period during which CGOCEANO and NASA were changing over to TIROS as a source of platform positions. NIMBUS was being de-emphasized; the NASA position monitoring equipment and evaluation programs were thus preoccupied by TIROS data. As a result, the position data for the SARP evaluation period were sparse.

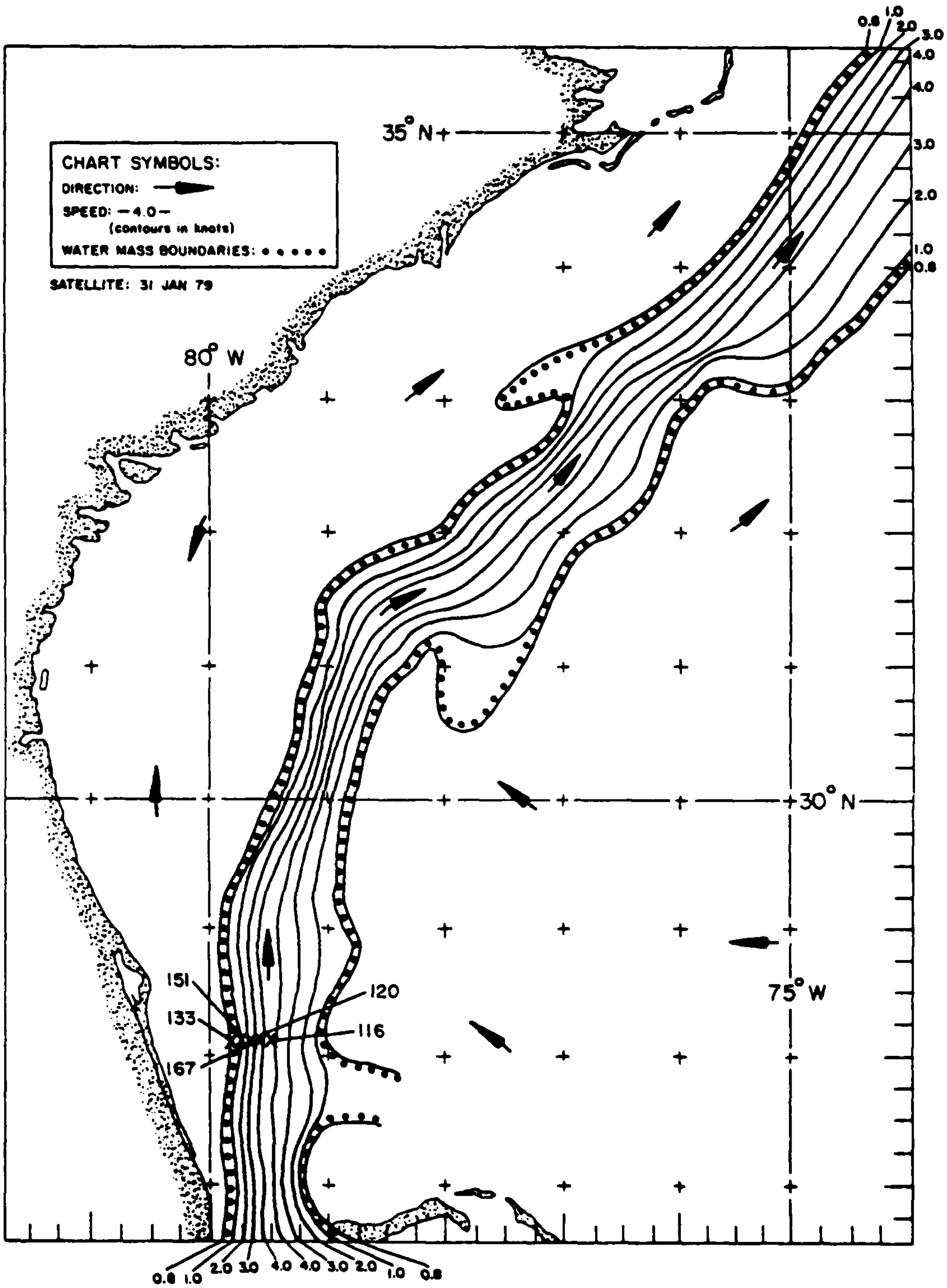
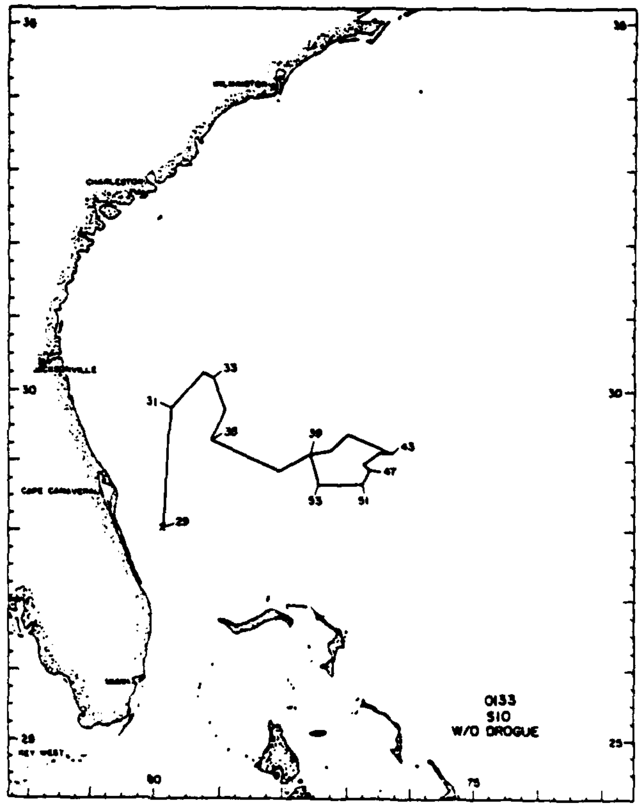


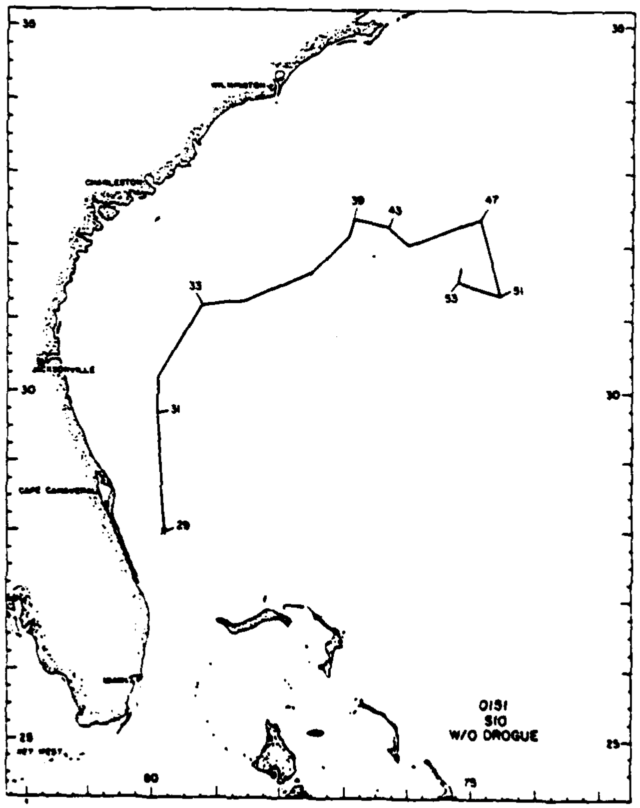
FIGURE 3-3. Release Sites in 1979.

Plots of the buoy trajectories during the 1979 SARP evaluation period are shown in Figure 3-4(a) through (e). The plotted positions are essentially raw data, with only obviously bad positions eliminated. Two criteria were used for this process. The first was based on the NASA-provided quality factor, a statistical index that indicates what confidence can be placed in a given position. Unfortunately, the results of this test were frequently inconclusive; thus it was necessary to examine the raw trajectories and calculated velocities for erroneous positions. Data which resulted in erratic behavior, such as rapid 180° shifts in buoy direction were discarded. Admittedly, the second criterion is subjective but, recognizing the complex dynamics of the study area, questionable positions were retained. For three of the buoys (116, 120 and 167), no usable positions were recorded for the launch date (29 January), as a result the records begin on 30 January.

The surface flow field suggested by the buoy tracks is indeed complex, with the track of buoy 133 (Figure 3-4a) indicating the most dramatic movement. It was released near the western boundary of the Gulf Stream, crossed the Stream and exited to the east. There is no clear evidence from satellite imagery for any large-scale flow feature which would cause this motion (or the loop in the track of 120, Figure 3-4d). Unfortunately, satellite imagery in the study area for the month of February was obscured by winter cloudiness and, as a result, the Gulf Stream could not be clearly seen (GULFSTREAM, 1979).

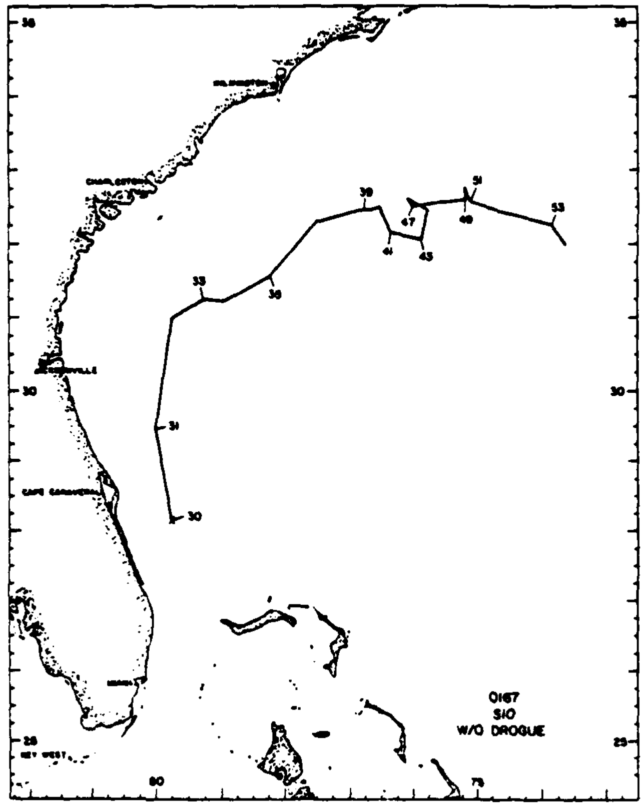


(a) 0133

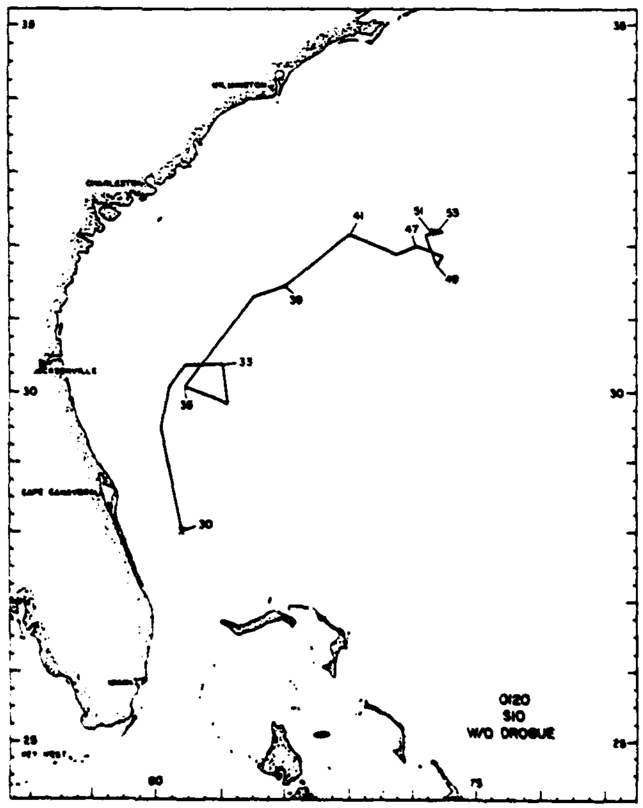


(b) 0151

FIGURE 3-4. 1979 Buoy Tracks for the SARP Drift Evaluation Period: (a) 133, (b) 151, (c) 167, (d) 120 and (e) 116. Continued on next two pages.

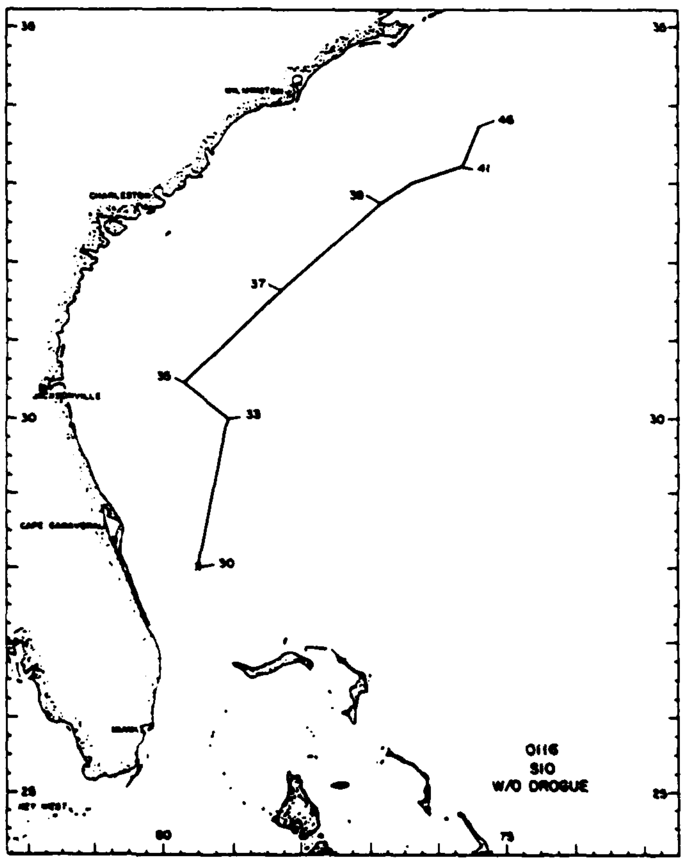


(c) 0167



(d) 0120

FIGURE 3-4 (Cont'd). 1979 Buoy Tracks for the SARP Drift Evaluation Period: (a) 133, (b) 151, (c) 166, (d) 120 and (e) 116.



(e) 0116

FIGURE 3-4 (Cont'd). 1979 Buoy Tracks for the SARP Drift Evaluation Period: (a) 133, (b) 151, (c) 167, (d) 120 and (e) 116.

Although the SARP drift evaluation period ended on 22 February (JD 53), the 5 buoys provided positions for a considerable period. For example, buoy 120, which transmitted for the longest period, provided positions into December 1979. It was eventually recovered by a fisherman near Bermuda and returned to R&DC (with the assistance of USCGC DECISIVE and the Bermuda representative of the Office of Naval Research). It was refurbished by SIO and used again in 1981.

Plots of the entire buoy tracks are shown in Appendix B.

b) 1980. Five of the 6 TODs released in 1980 transmitted during the entire 25-day (8 February-6 March) SARP drift evaluation period. As in 1979, all of the buoys were released from USCGC EVERGREEN at approximately 28°N; the spacing of the release sites across the Gulf Stream was, however, quite different (Figure 3-5). One buoy (2647) was released near the western wall, three (2645, 2648 and 2649) were placed near the core and two (2644 and 2646) were released to the east of the core. The launch positions were chosen with the assistance of a preliminary expendable bathythermograph (XBT) survey and sea surface temperature data from ART overflights.

After the launch positions, which were determined using LORAN-C aboard USCGC EVERGREEN, all of the buoy positions were recorded by CGOCEANO using both the LUT and Service ARGOS. During the drift evaluation period an average of 3 to 4 good fixes per day was received for each of the transmitting buoys.

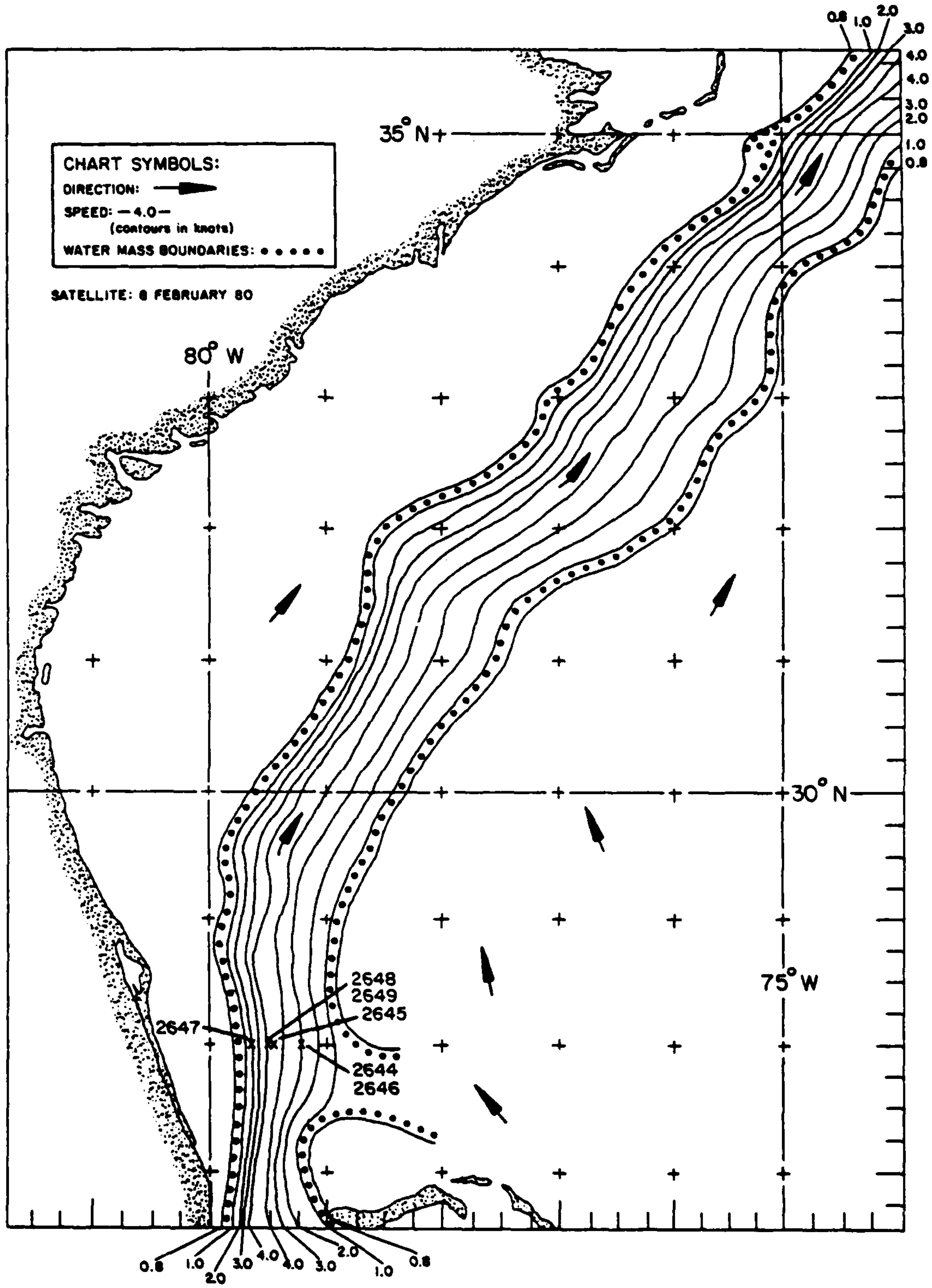


FIGURE 3-5. Release Sites in 1980.

Four of the six buoys were fitted with window shade drogues. Drogued PRL buoys were released at the west wall (2647), near the core (2645 and 2648) and east of the core (2644). Of the remaining two buoys, one (2646) was an undrogued PRL buoy which was released with 2644 and the other (2649) was an undrogued SIO buoy which was launched with 2645 and 2648.

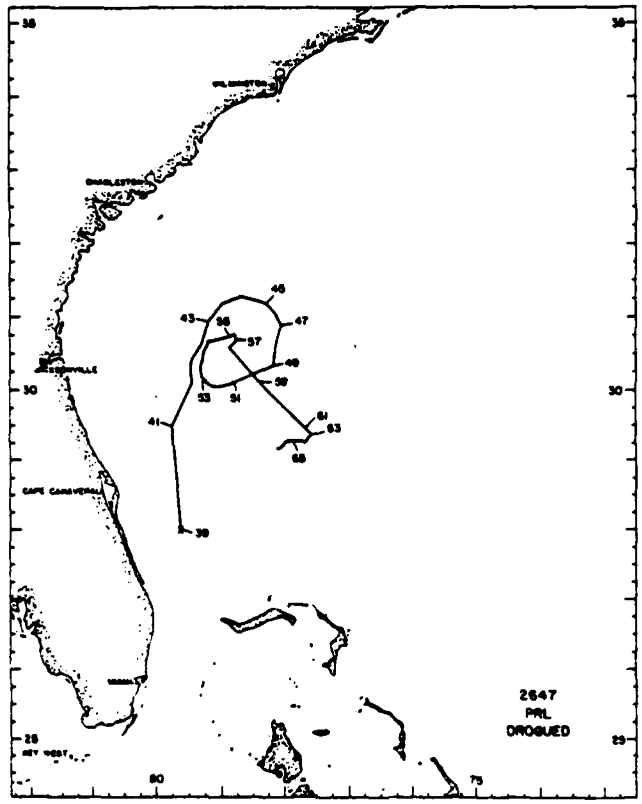
With the exception of 2648, the "on/off" sensor on the drogued buoys indicated that the drogues remained attached during the entire drift evaluation period. Buoy 2648 began to malfunction immediately after it was launched. The battery voltage dropped precipitously and the drogue indicator never registered in the "on" position. It was recovered one week after the launch date; the drogue was still attached. The malfunction of 2648 was particularly unfortunate because it was released at approximately the same location as 2645, also a drogued PRL buoy, to investigate the separation of identical buoys in the study area. After recovery, buoy 2648 was returned to PRL, refurbished and used again in the 1981 experiment.

As in 1979, the near surface flow field suggested by the buoy trajectories (Figure 3-6a through e) was quite complex. The buoy released near the west wall (2647) crossed the Gulf Stream, made a large clockwise loop and proceeded to the southeast (Figure 3-6a). There is no firm satellite imagery data to suggest any large-scale features that would cause this motion, except that there is some evidence (Figure 3-7) that a cold core eddy was interacting with the Gulf Stream in the vicinity. Regrettably, winter cloudiness again obscured portions of the study area for the middle to end of February. As a result, the position of the thermal front in the vicinity of 2647 on Figure 3-7 had to be estimated. Figure 3-7 is a portion of the NOAA-provided Gulf Stream analysis (22-27 February 1980) which results from the TIROS-N-AVHRR (Advanced Very High Resolution Radiometer). The clockwise movement of 2647 is particularly puzzling, recognizing that cold core eddies rotate in the counter-clockwise direction. This could be a result of wind events but further investigation is not germane to this analysis.

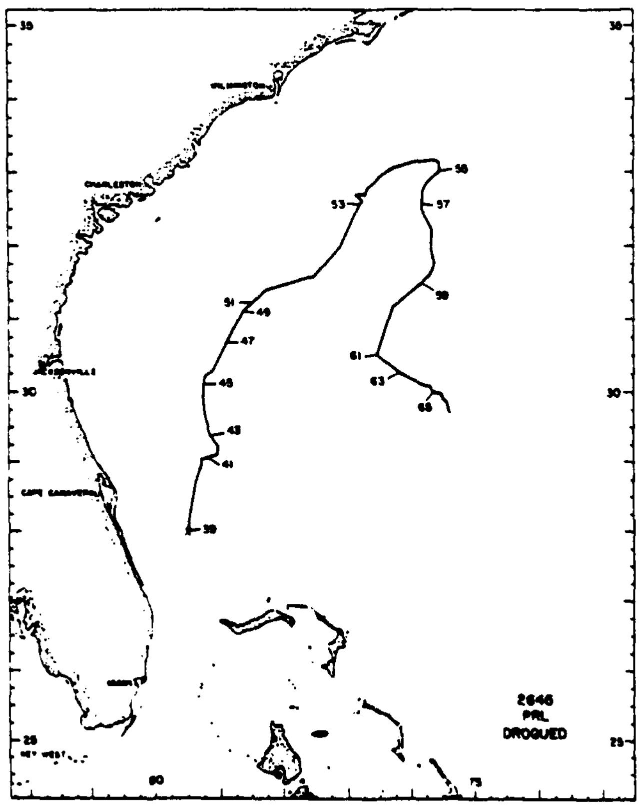
Figure 3-7 also provides an important clue for the fate of 2646. A band of warm water is shown connected to the Gulf Stream at 27.5^{o}N and 79^{o}W which projects to the southeast toward Great Abaco Island. This feature is coincident with the southeast movement of buoy 2646 during the same period. Within this feature, the buoy speed varied somewhat but was in the range of .7 (.36ms^{-1}) to 1.2 kts (.62ms^{-1}).

The digitized Gulf Stream boundary file provided to Atlantic Area (Aso) by CGOCEANO and which defines the GULF file does not extend to the south of 28^{o}N; thus, the observed warm water feature in which 2646 traveled is not contained in GULF. Buoy 2646 beached on Great Abaco shortly after the conclusion of the 1980 drift evaluation period.

Four of the buoys (2644, 2645, 2647 and 2649) continued to provide positions for a considerable period after the end of the SARP drift evaluation. Buoys 2647 and 2649 transmitted nearly until the end of 1980 and 2644 and 2645 transmitted well into 1981. Plots of the entire buoy trajectories are shown in Appendix B.

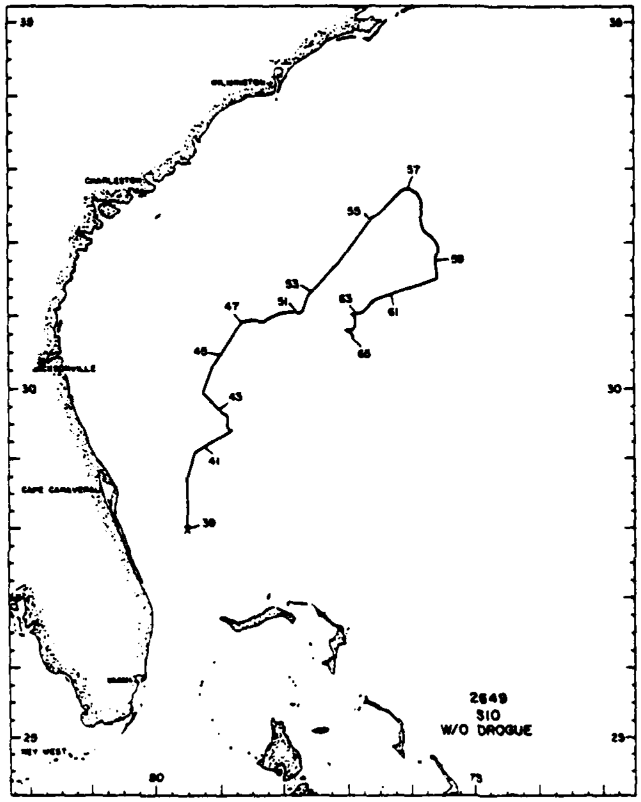


(a) 2647

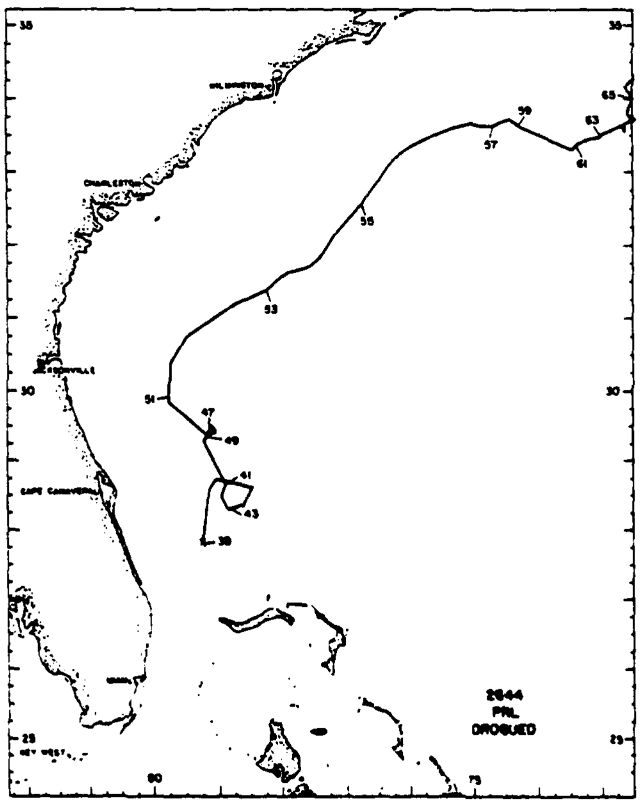


(b) 2646

FIGURE 3-6. 1980 Buoy Tracks for the SARP Drift Evaluation Period: (a) 2647, (b) 2645, (c) 2649, (d) 2644, and (e) 2646. Continued on next two pages.

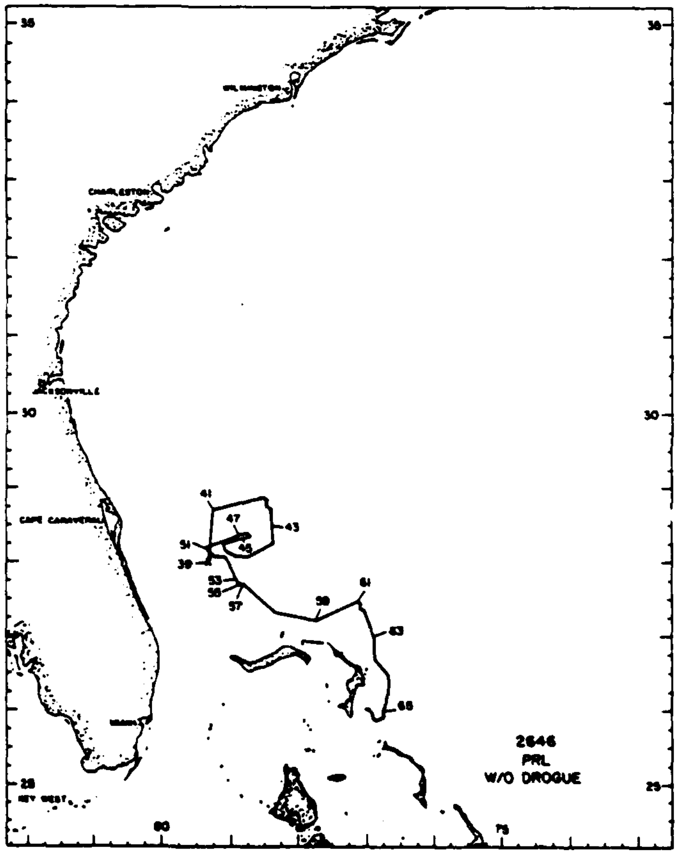


(c) 2649



(d) 2644

FIGURE 3-6 (Cont'd). 1980 Buoy Tracks for the SARP Drift Evaluation Period: (a) 2647, (b) 2645, (c) 2649, (d) 2644, and (e) 2646.



(e) 2644

FIGURE 3-6 (Cont'd). 1980 Buoy Tracks for the SARP Drift Evaluation Period: 647, (b) 2645, (c) 2649, (d) 2644, and (e) 2646.

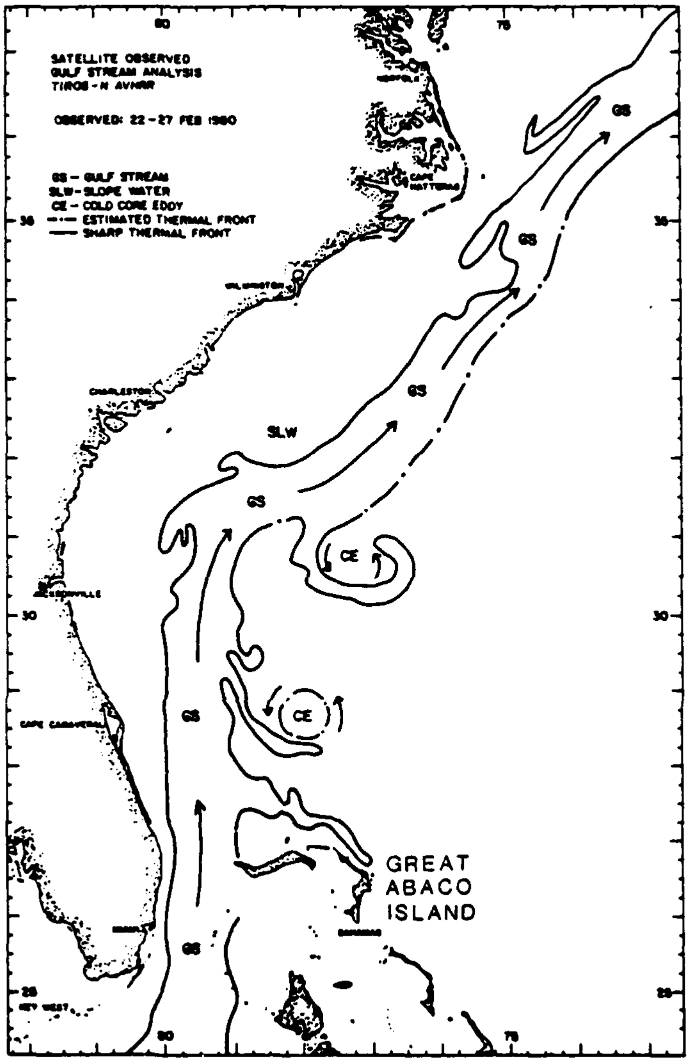


FIGURE 3-7. Gulf Stream Analysis from TIROS-N AVHRR data provided by National Environmental Satellite Service (NESS) for the Period 22-27 February 1980 (JD53-58).

Although there are some evident differences, the tracks of two of the three surviving buoys released near the core (2645 and 2649) were qualitatively quite similar. This similarity is particularly noteworthy because 2645 was a PRL buoy with its drogue still attached and 2649 was an SIO hull without a drogue. The similarity of their trajectories for the relatively short SARP drift evaluation period lends some support to a claim that the type of buoy hull used and whether or not a drogue is attached are not of critical importance to the results of this three-year study. The effort to compare 2649 to the drift of two drogued PRL buoys failed with the demise of 2648.

About 25 February (JD 56) at approximately 33°N and 76°W, 2645 and 2649 became entrained in a tail of the Gulf Stream which was interacting in a very complex manner with a cold core eddy located at 31°N and 77°W (Figure 3-8). The tracks of the two buoys (Figures 3-6b and c) are remarkably similar to the warm water band which proceeds to the southwest.

Buoys 2644 (Figure 3-6d) and 2646 (Figure 3-6e), which were released at the same location east of the Gulf Stream core, showed dramatically divergent movement. The two buoys, one drogued (2644) and the other without a drogue (2646), moved together for several days until, on 10 February (JD 41), they entered a region in which a cold core eddy was seen interacting with the Stream approximately two weeks previously (GULFSTREAM, January 1980). There is no evidence from satellite imagery for the existence of an eddy which would cause the observed clockwise loop in both buoy tracks.

c) 1981. The two buoys released in the 1981 SARP drift evaluation were buoys recovered following the two previous years' experiments. One undrogued SIO hull with NIMBUS electronics (120) and a drogued PRL TIROS buoy were launched together at approximately 28°N near the center of the Gulf Stream (Figure 3-9) by USCGC VIGOROUS.

Buoy 120 provided an average of one good position per day for the entire 23-day (3 February-25 February) 1981 SARP drift evaluation period. There was, however, one four-day gap in the data record beginning on 21 February (JD 52). The positions were provided to R&DC by SIO.

Buoy 2648 failed on 10 February (JD 41), one week into the study period. The reason for the failure is uncertain because the battery voltage was within acceptable bounds for the entire buoy lifetime. Initially, the drogue indicator showed that the drogue was attached, but one day after the launch the indicator showed that the drogue had detached. In the 1980 experiment, when buoy 2648 was used for the first time, a precipitous voltage drop and a drogue indicator which never registered in the on position led to recovery of the buoy one week after launch. The drogue was still attached to the buoy in the normal manner. From this previous behavior, no definitive conclusion can be drawn on the fate of the drogue during the 1981 experiment. It can only be said that there is some doubt as to whether or not the drogue detached as indicated.

Before 2648 failed, it provided an average of one good fix per day. The buoy was tracked by CGOCEANO who provided the data to R&DC.

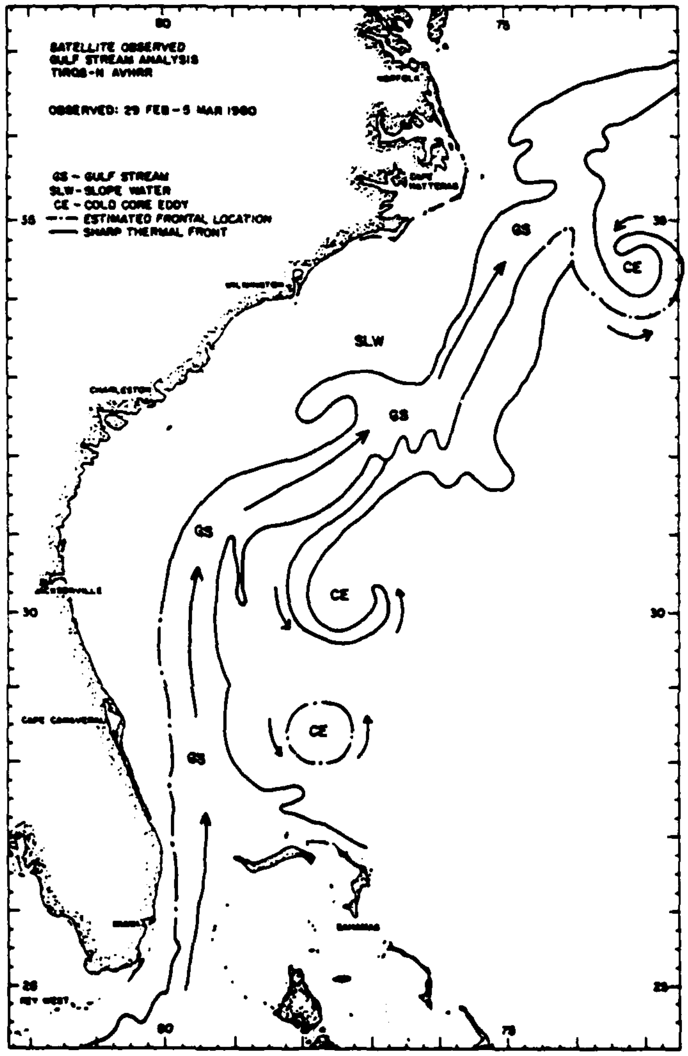


FIGURE 3-8. Gulf Stream Analysis from TIROS-N AVHRR for the Period 29 February to 5 March 1980 (JD 60-65).

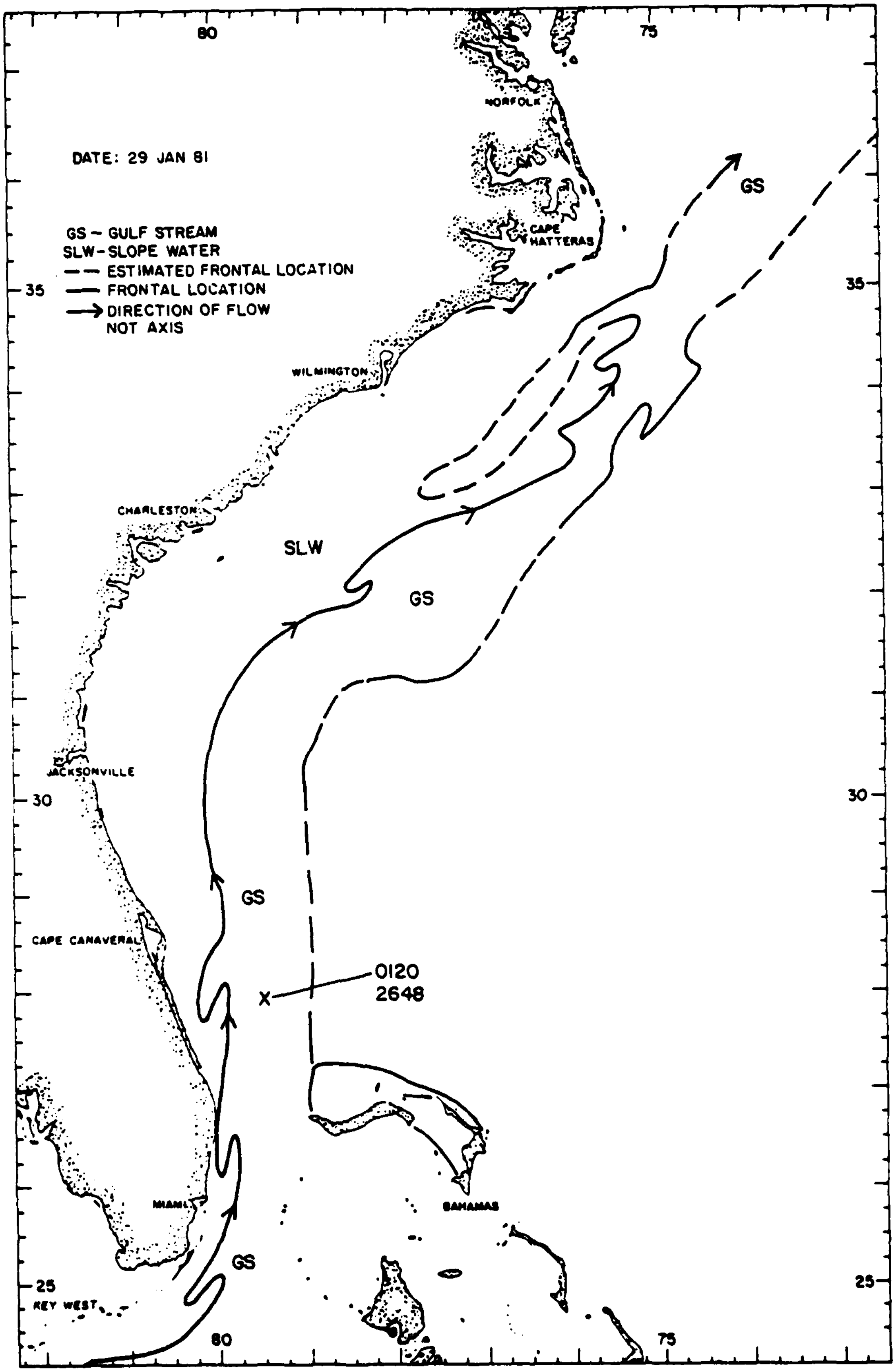


FIGURE 3-9. Release Site in 1981 plotted on the Oceanographic Analysis provided by NESS.

For the short period during which both buoys transmitted, the tracks (Figure 3-10) were remarkably similar, including a nearly coincident clockwise loop in the vicinity of 30°N and 79°W. A possible cold core eddy (Figure 3-11), was observed in the vicinity of 30°N and 78°W on 12 February (JD 43). These counter-clockwise loops are similar to those observed in 1981, when buoys 2644 and 2646 traced a clockwise loop in the region where the Gulf Stream was interacting with a cold core eddy. This is another example of an undrogued buoy with an SIO hull moving in a similar manner with a PRL buoy, although the fate of the drogue on the PRL buoy is uncertain.

3.3 SARP Predictions

There were slight differences in emphasis in each of the three years of the SARP drift evaluation effort. In 1979, when the program was just beginning, the major sampling effort was designed to evaluate the role of wind driven current, particularly the differences between using predicted winds and analysis winds. In 1980 the effort to isolate the effect of the wind on the drift predictions continued, but the experiment was expanded to include SARP predictions up to 120 hours. The 1980 experiment provided the most data. The 1981 experiment, which was conducted with two recycled buoys, was focused primarily on the region where the GULF and FLDA files overlap. The details of the experiments are presented in the following sections.

3.3.1 1979 Predictions

During the 1979 experiment, primary emphasis was placed on the role of wind driven current in the SARP drift predictions, particularly, the sensitivity of the drift predictions to the type of wind input. For each simulated SAR incident, three separate runs, using different wind inputs, were made: analysis wind, predicted wind, and no wind. The analysis winds, determined by FNOC using observations from a variety of sources, represent the best available wind information. In the predicted wind case, which is more representative of an actual SAR incident, a combination of predicted and analysis winds (as described earlier) was used. Typically, 12 hours of predicted winds were used for a 24 hour drift prediction. For the remaining 60 hours of wind data required for the calculation (including 48 hours prior to the time of the SAR incident), analysis winds were utilized. The final case was a SARP drift prediction made using no wind input and, as a result, the drift is due solely to the sea current. It should be emphasized that, for all of the drift predictions, leeway was assumed to be zero; thus, wind enters the SARP drift computation only as an input to the locally-generated wind current.

For two reasons it was necessary to recompute E (total probable error) to make the 1979 data consistent with the two succeeding years. First, several combinations of initial position error (X) and search craft position error (Y) were used in the early SARP runs. It was, therefore, necessary to recompute E to reflect the fundamental assumption (Section 2.2) that X=Y=3 nmi. Second, a new formulation for the total drift (TD) was instituted between the 1979 and 1980 experiments. In 1979, TD was taken to be the straight line distance between the initial position and the datum. Starting with the 1980 data, TD was calculated using the summation of the several drift segments used in SARP; that is, allowance was made for a path between the initial position and the datum which is not necessarily straight.

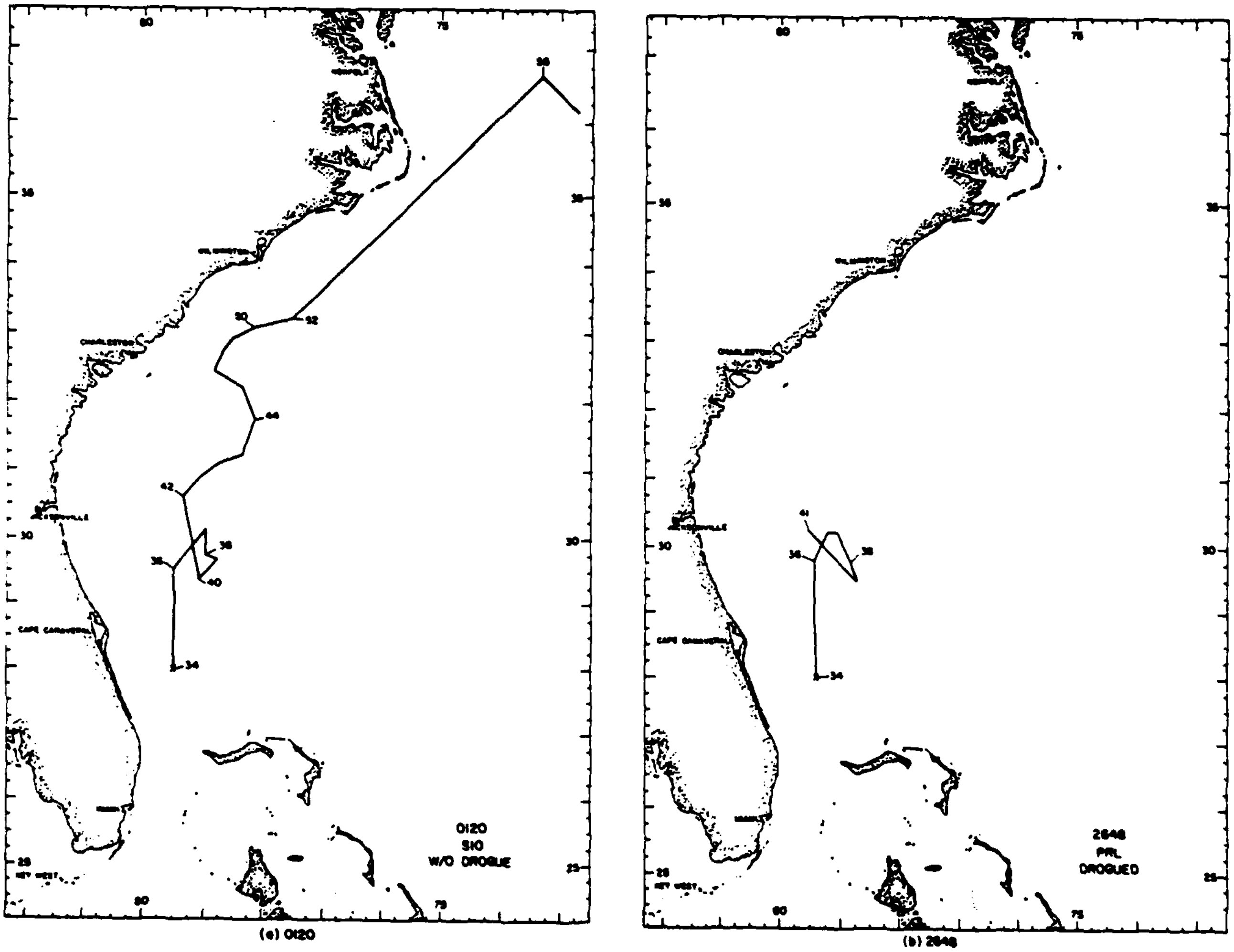


FIGURE 3-10. 1981 Buoy Tracks for the SARP Drift Evaluation Period: (a) 0120 and (b) 2648.

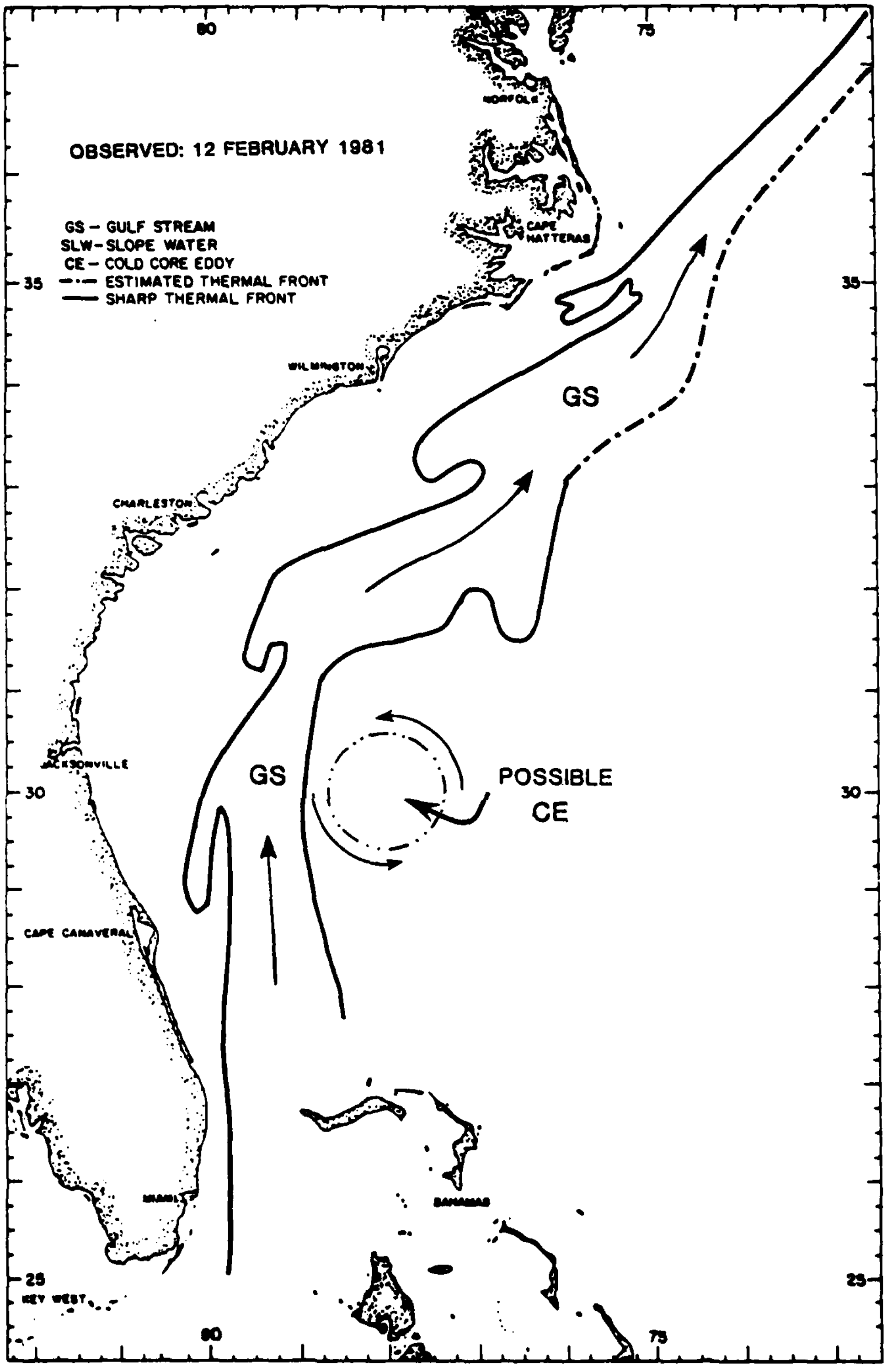


FIGURE 3-11. Oceanographic Analysis for the date 12 February 81 (JD 43) provided by NESS.

Correcting the value for E was a simple matter of using Equation 2-1. The values of X and Y were set equal to 3 nmi and the total drift was recomputed using the SARP output which provides intermediate position for each of the time intervals.

The positions used by Atlantic Area (Aso) as the last known position and incident DTG of a simulated SAR case were taken from satellite positions recorded at CGOCEANO's LUT and sent via priority message. The goal was to get the buoy position and DTG to Aso within 12 hours so that predicted winds, which are replaced with analysis winds every 12 hours, could be used in the predictions. All of the drift predictions in 1979 were for a drift interval of 24 hours. The buoy positions provided by CGOCEANO were supplemented by positions provided to R&DC by SIO several months later. These SIO positions were used to fill in some data gaps so that more positions could be used to evaluate the predicted buoy drift.

3.3.2 1980 Predictions

The 1980 experiment provided the most SARP predictions for drift evaluation, primarily due to the change from NIMBUS to TIROS drifters. The evaluation of the type of wind used for the SARP prediction continued; thus for each SARP run three wind conditions were used: analysis wind, predicted wind, and no winds. The largest number of predictions was made for a drift interval of 24 hours, although the effort was expanded to include drift intervals of 48, 72, 96, and 120 hours.

As in 1979, CGOCEANO provided excellent support for the experiment. They tracked the buoys using both the LUT and Service ARGOS and provided positions and DTGs to Aso via priority message, in addition to providing the data to R&DC.

The buoy position reporting procedure resulted in some round-off error because the positions were reported to Aso in degrees and decimal degrees, and thus had to be converted to the degrees/minutes form used for the SARP input. This round off error was negligible ($< .25$ nmi), and relatively few transcription errors occurred which required that the data (drift predictions) be discarded.

3.3.3 1981 Predictions

The focus of the 1981 experiment, conducted using two buoys recovered following previous experiments, was considerably different from 1979 and 1980. No longer was any attempt made to distinguish between predicted and analysis winds; thus only two wind cases were run for each SARP drift prediction: no wind and analysis winds. Special attention was given to the current files used in the area where the GULF file overlaps the FLDA file. In this region, unless the GULF override is specified, the FLDA file takes precedence. To test the sensitivity of the SARP drift predictions to this GULF override option, two runs were made for each wind case, with and without specifying the GULF option. As a result, four SARP drift predictions were made for each buoy position and DTG used in the experiment. For all of the SARP runs, a drift interval of 24 hours was used.

Because no predicted winds were used in 1981, it was not necessary to provide real time buoy positions to Aso. One buoy, a TOD (2648), was tracked by CGOCEANO while the other, a NIMBUS buoy (120), was tracked by SIO and NASA; in both cases, the positions were mailed to R&DC. Finally, R&DC provided listings of the positions to Aso so that the SARP-runs could be made. As discussed earlier, the analysis winds and GULF current file are stored by Aso for 90 days and 2 years, respectively. Thus, the SARP runs could be made using the archived current and wind data for the appropriate time period.

3.3.4 Summary of SARP Drift Predictions

Table 3-1 summarizes the drift predictions evaluated during the three years of this study. The 680 drift predictions are separated according to both drift interval and type of wind input. Of the three years, 1980 contains the most data, as well as the only drift intervals of more than 24 hours. For the entire study, however, the 24-hour drift interval dominates the data. Note that, although 680 drift predictions were evaluated, in most cases three wind conditions were run for each simulated SAR incident. As a result, the 680 figure does not represent the number of completely independent tests.

TABLE 3-1. Number of SARP drift predictions for each year according to drift intervals and type of wind input. A, P and N indicate, respectively, analysis wind, predicted wind and no wind cases.

	DRIFT INTERVAL (HR)														
	24			48			72			96			120		
YEAR	A	P	N	A	P	N	A	P	N	A	P	N	A	P	N	TOTALS
1979	28	10	25	0	0	0	0	0	0	0	0	0	0	0	0	63
1980	93	81[1]	86	33	39[2]	33	19	23	19	19	24	19	15	15	15	533
1981	42	0	42	0	0	0	0	0	0	0	0	0	0	0	0	84
TOTALS	163	91[1]	153	33	39[2]	33	19	23	19	19	24	19	15	15	15	680

Notes:
1. In 1980 two SARP runs were made for a drift interval of 23 hours and are included in the 24-hour data.
2. In 1980 five SARP runs were made for a drift interval of 40 hours and are included in the 48-hour data.

4.0 ANALYSIS AND RESULTS

4.1 Introduction

The primary goal of the data analysis was to evaluate the accuracy of the SARP drift predictions. The comparison of the SARP drift predictions with the buoy tracks proceeded on two levels. The first and more fundamental (Section 4.2) is an analysis of the success of a prediction in terms of whether or not the search target (buoy) was within the search area defined on the SARP output. The second method, described in Section 4.3, is the contingency analysis which was used to examine the performance of the sea current files employed in the drift predictions, as well as the performance of the SARP drift predictions for various drift intervals.

4.2 Success Analysis

The success of a SARP drift prediction was determined by whether or not the buoy was within the search area at the time of the predicted datum. Because the buoy positions were determined by the satellite at irregular intervals, it was necessary to interpolate the buoy tracks to arrive at a position to coincide with the time of the predicted datum; a linear interpolation scheme was utilized. Rarely was it necessary to interpolate over an interval of greater than 24 hours and, typically, the interpolation interval was less than 12 hours.

As was discussed previously, the search area is constructed by circumscribing a square around a circle whose radius is equal to the first search radius (R). As a practical matter, it makes little difference whether the square or circular search area is used as a success criterion because, of the 680 drift evaluations, there were only five instances in which the buoy was outside of the circle yet in the square search area.

Table 4-1 shows the success ratio, defined as the number of successes over the number of opportunities, for the entire experiment. The data are separated according to drift interval, wind type and specified options. Several results of particular interest are as follows.

TABLE 4-1. *Success ratio, defined by the number of times the interpolated buoy position was in the search area over the number of opportunities; the number in parentheses is the ratio expressed as a decimal.*

	DRIFT INTERVAL (HR)					
	24	48	72	96	120	TOTALS
No Winds	10/132 (.076)	1/33 (.030)	0/19 (.000)	1/19 (.053)	0/15 (.000)	12/218 (.055)
Analysis Winds	13/142 (.092)	0/33 (.000)	0/19 (.000)	0/19 (.000)	0/15 (.000)	13/228 (.057)
Predicted Winds	7/91 (.077)	0/39 (.000)	1/23 (.043)	1/24 (.042)	0/15 (.000)	9/192 (.047)
No Winds and Gulf Option Specified	4/21 (.190)					4/21 (.190)
Analysis Winds and Gulf Option Specified	3/21 (.143)					3/21 (.143)
TOTALS	37/407 (.091)	1/105 (.010)	1/61 (.016)	2/62 (.032)	0/45 (.000)	41/680 (.060)

1. The overall success ratio was .060. This means that in only 6% of the tested SARP-runs was the buoy within the predicted search area.

2. While the ratio for a drift interval of 24 hours was .091, it was considerably lower (.015) for predictions of > 24 hours.

3. Based solely on the success, the results are not sensitive to the type of wind input to SARP. A more detailed analysis of the wind inputs are presented later as part of the contingency analysis.

A detailed examination of the 1981 data, in which the effect of specifying the Gulf Stream option was examined, shows (Table 4-2) that there is little apparent difference in the results. Although the overall success (.143) was higher than the cumulative data for the entire experiment, the number of opportunities was small (84).

TABLE 4-2. Success ratio, defined by the number of times the interpolated buoy position was in the search area over the number of opportunities. The number in parentheses is the ratio expressed as a decimal. All data are for a 24-hour drift interval.

No winds	2/21 (.095)
Analysis winds	3/21 (.143)
No winds Gulf Stream option specified	4/21 (.190)
Analysis winds Gulf Stream option specified	3/21 (.143)
TOTAL	12/84 (.143)

4.3 Contingency Analysis

Further analysis of the data was undertaken using the non-parametric, statistical-method, contingency table for independent samples (Woolf, 1968). This method was chosen because it requires no assumptions about the data distribution and can handle discrete data. A recent application of this statistical analysis can be found in Remondini et al. (1981).

In this test, the null hypothesis (H_0) is that rows and columns are independent; i.e.,the probability that an individual measurement will occur in any particular row is unaffected by the particular column to which it belongs. To test the hypothesis, one calculates the expected value (E_{IJ}) for each cell by multiplying together the sums of it's particular column and row and dividing by the sum of the matrix. After each cell's expected value is calculated, the procedure is then to calculate the chi square value (x^2), and to determine the probability (P) associated with that value by using the standard chi square table, with the degrees of freedom (df).

$$E_{IJ} = \frac{\left[\sum_{i=1}^{i=r} O_{iJ}\right]\left[\sum_{j=1}^{j=k} O_{Ij}\right]}{\sum_{i=1}^{i=r}\sum_{j=1}^{j=k} O_{ij}}$$

$$x^2 = \sum_{i=1}^{i=r}\sum_{j=1}^{j=k} \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

where

O_{ij} = observed number of cases in the ith row and the jth column

E_{ij} = expected number of cases in the ith row and the jth column

$\sum_{i=1}^{i=r}\sum_{j=1}^{j=k}$ directs one to sum over all rows (r) and all columns (k) i.e. over all cells.

The number of degrees of freedom is calculated using

df = (rows - 1) (columns - 1).

The acceptable probability of incorrectly rejecting H_0 is called the level of significance (α). If P is less than or equal to α , then H_0 is rejected. The α for this study is 0.05, which means that there is a 5% chance of rejecting H_0 when H_0 is true.

The interpretation of the results of this test is based on the following rationale. If the difference between the observed frequencies and the expected frequencies (shown in parenthesis in the tables) are quite small, then the x^2 value is also small; therefore, H_0 cannot be rejected. The H_0 is that the sets of characteristics are independent of one another. Alternatively, if the differences between the observed and expected

frequencies are large, then X^2 is also large. This is interpreted to mean that the groups differ with respect to these characteristics.

Finally, there are certain limitations when using this test. When either the number of columns or rows is greater than two, and therefore, df is greater than 1, no more than 20% of the cells may have an expected frequency less than 5. Furthermore, no cell may have an expected frequency less than one.

4.4 Performance Criteria

Four performance criteria were established for use in the contingency analysis. They were calculated using data (last known position and datum) from the SARP output and interpolated buoy positions.

4.4.1 Bearing Difference

The bearing difference (BD) is the difference between the direction of predicted movement and the direction of actual buoy movement. It is defined by

$$BD = B_p - B_A$$

where,

B_p = bearing from last known position (LKP) to the datum (direction of predicted net drift)
B_A = bearing from LKP to interpolated buoy position (direction of actual net drift).

BD is a good measure of the directional accuracy of a prediction and can point out any systematic errors, for example, a sea current file which frequently predicts movement to the right of actual target movement. The absolute value of BD is a measure of the total directional error.

4.4.2 Relative Drift Error

The relative drift error (RDE) is

$$RDE = (D_p - D_A)/D_p \qquad (4\text{-}1)$$

where,

D_p = straight line distance between LKP and datum
D_A = straight line distance between LKP and interpolated buoy position.

RDE is, thus, a measure of the accuracy with respect to drift distance. RDE is normalized to D_p so that direct comparisons can be made between cases involving different drift magnitudes. A negative RDE indicates that the predicted drift was an underestimate while a positive number indicates an overprediction.

4.4.3 R-factor

R-factor, the number of first search radii from datum to the buoy position, is calculated as the straight line distance from datum to the corresponding buoy position divided by the first search radius. It is a good measure of the total accuracy of the prediction system, but has a property which is misleading at times. For very slow current regimes, the position errors and safety factors involved could define a first search radius that does not permit the drift to play any significant role, i.e., is very small. This is adequate for operational purposes, but can hamper analysis of the accuracy of the current files, because a small R can lead to a misleadingly large R-factor.

Another drawback of R-factor as a measure is that it is a non-diagnostic measure; that is, it addresses the overall accuracy of the prediction without addressing bearing or speed accuracy.

4.4.4 Effectivity

Effectivity (E_f) is a measure of whether a prediction is useful or harmful. E_f is defined as the difference in nautical miles between the actual net drift and the distance between datum and the interpolated buoy position. It quantifies whether the LKP or the datum is closer to the actual buoy position.

4.5 Data Tests

Using the contingency analysis, the data were checked for relationships between key experimental variables (i.e., wind type, prediction times, and current files) that could bias the analysis results. This check was done for the combined 1979 and 1980 data, a homogeneous (includes both analysis and predicted wind SARP predictions) data set which constitutes the bulk of the collected data.

4.5.1 Prediction Time vs. Wind Type

A comparison was done for prediction time vs. wind file to determine if difference in performance of different wind files could be due to different prediction times or vice versa. The wind files are used to derive the surface wind-driven current; therefore the "no wind" means no surface wind-driven current was used to make the drift prediction. The "wind" means either analysis or predicted winds were used to calculate the surface wind-driven current. The categories used for prediction time were 24, 48, 72, 96, and 120 hour predictions.

The results of the analysis (Table 4-3) show that the differences between the expected and observed values are quite small and the value of χ^2 is 0.5577. As a result, the null hypothesis (H_0), which states that the type of wind used and the prediction time are independent, cannot be rejected.

TABLE 4-3. Prediction Time vs. Wind Type for the 1979-1980 data.

The observed and expected values (in parenthesis) are presented for the Wind and No Wind cases for all of the prediction times. P is the probability and df is the degrees of freedom.

	24 hr	48 hr	72 hr	96 hr	120 hr	Total
NO WIND	111 (107.4)	33 (33.4)	19 (20.4)	19 (20.7)	15 (15.1)	197
WIND	210 (213.6)	67 (66.6)	42 (40.6)	43 (41.3)	30 (29.9)	392
TOTAL	321	100	61	62	45	589

$\chi^2 = 0.557$

$df = 4$

$.95 < P < .98$

4.5.2 Current File vs. Wind Type

For this analysis the wind categories were the same as those in Section 4.5.1. The current files for which there were adequate data to perform the contingency analysis were NAVO, FLDA, and CORE. In many cases several sea current files were used during one SARP drift prediction. However, to simplify the analysis, only those predictions in which a single current file was utilized were evaluated. The H_0 is that predictions using a particular current file are independent of the wind file used. The results (Table 4-4) are inconclusive in that H_0 cannot be rejected at the 0.05 significance level but P is relatively low. For the purpose of this analysis, we will accept the H_0 as there is no reason to suspect a dependence between wind type and current file.

TABLE 4-4. Current File vs. Wind Type for the 1979-1980 data.

The observed and expected values (in parenthesis) are presented for the Wind and No Wind cases for each of the sea current files for which sufficient data were available. P is the probability and df is the degrees of freedom.

	NAVO	FLDA	CORE	TOTAL
NO WIND	81 (82.9)	46 (48.3)	24 (19.8)	151
WIND	154 (152.1)	91 (88.7)	32 (36.2)	277
TOTAL	235	137	56	428
	$\chi^2 = 1.650$ df = 2 $0.3 < P < 0.5$			

4.5.3 Prediction Time vs. Current Files

Predictions using a single current file were checked for independence of prediction time. The current files were aggregated so each file, (NAVO, FLDA, and CORE) constituted a bin. For the first comparison, each prediction time constituted a bin. The results (Table 4-5) suggest that there might be a relation. Rebinning prediction time into three bins: 24-48 hours, 72 hours, and 96-120 hours H_0 can be rejected at the .05 significance. Dropping the 72 hour bin H_0 can be rejected at the 0.01 level. From other binning schemes, in Table 4-5, it appears that the 24 and 48 hour prediction times are clearly independent of current files. There is some doubt about the 72 hour predictions; therefore, only the 24 and 48 hour predictions may be used as a data base for current file analysis. Any analysis of the effect of longer prediction times must be done separately for each current file.

4.5.4 Summary of Data Tests

Several important conclusions, which guided the SARP performance tests, can be drawn from the preceding data tests. They are:

a) the type of wind used and the prediction time are independent.

b) although there is no reason to expect a dependence between wind type and current file, the results of the contingency analysis are inconclusive. As a result, independence cannot be proven and must be assumed.

c) only the 24 and 48 hour prediction times are clearly independent of the current files and, thus, they constitute the data base for the performance tests of the current files.

d) any analysis of the effects of prediction times longer than 48 hours must be done separately for each current file.

TABLE 4-5. Current File vs. Prediction Time for the 1979-1980 Data.

N is the number of observations, P is the probability, and df is the number of degrees of freedom. The data bins for each test are listed under the respective headings.

Current Files	Prediction Times (hr)	χ^2	df	P	N
NAVO, FLDA, CORE	24, 48, 72, 96, 120	11.944	8	$.1 < P < .2$	422
	24-48, 72, 96-120	11.246	4	$.02 < P < .05$	422
	24-48, 96-120	11.207	2	$.001 < P < .01$	388
	24, 48, 72	0.640	4	$.95 < P < .98$	377
	72, 96-120	5.680	2	$.05 < P < .10$	79
	48, 72, 96-120	8.746	4	$.05 < P < .1$	149

TABLE 4-6. Absolute Value of the Bearing Difference vs. Wind Type

Data are for the period 1979 through 1981. N is the number of observations, P is the probability, and df is the number of degrees of freedom. An "X" indicates which bins were used for wind for each test.

No Wind	Analysis	Predicted	χ^2	df	P	N
X	X	X	37.869	34	$.3 < P < .5$	676
	X	X	12.618	17	$.7 < P < .8$	439
X	X		21.707	17	$.1 < P < .2$	484
X		X	22.822	17	$.1 < P < .2$	429
X	Anal & Pred		25.958	17	$.05 < P < .10$	676

4.6 The Effect of Using Winds in SARP Predictions

A wind of 15 knots blowing over the ocean with a fetch of over 100 miles for more than 8 hours will produce a current of 0.3 knots (SAR Manual). This wind driven current will move a search object a distance of 7.2 nautical miles in 24 hours. If a search unit knew the exact position of a distress vessel 24 hours before, had perfect navigation, and had perfectly taken into account all other currents and leeway, but ignored wind-driven current, the search unit might have to search up to 163 square nautical miles before finding the distress vessel. There is, therefore, no question about the need to include wind-driven currents in drift predictions. But is the system good enough at the present time to be of any assistance? Is there a systematic error that needs correcting or that is actually hindering present efforts? These and other issues are addressed in this section in which the performance of the SARP drift predictions is examined as a function of the wind type. The absolute bearing difference and the absolute value of the relative drift error are used as performance criteria. In addition, for a specific current file (NAVO), the effect of wind type on 24-hour SARP predictions is evaluated. All analyses are based on data from 1979 through 1981.

4.6.1 Absolute Bearing Difference vs. Wind Type

One measure of performance is absolute bearing difference (Section 4.4.1) between predicted and actual direction of drift. The absolute difference in bearing was calculated using the data from the SARP predictions and interpolated buoy positions. The results were then divided into 10 degree bins and compared to wind type. The null hypothesis is that the absolute difference in bearing is independent of the use of (and type of) wind file. It can be said with confidence that analysis and predicted winds perform the same in absolute directional accuracy (Table 4-6). The comparison of either "analysis" or "predicted" winds with the "no wind" is inconclusive. The fact that combining the "analysis wind" and "predicted wind" gives a lower probability suggests that there might be a difference, even though the null hypothesis cannot be rejected at the 0.05 significance level.

4.6.2 Absolute Value of the Relative Drift Error vs. Wind Type

Another measure of performance is the absolute value of the relative drift error. The relative drift error (Equation 4-1) is defined as the ratio of the difference between the predicted and actual straight line drift distance to the predicted straight line drift distance. The null hypothesis is that the relative accuracy in predicting drift distance is independent of the use of (and type of) wind file. The null hypothesis can be rejected in the cases of "no wind" vs. "analysis winds" and "no wind" vs. "predicted wind" (Table 4-7). The null hypothesis can be accepted with confidence in the case of "analysis wind" vs. "predicted winds".

TABLE 4-7. Absolute Value Relative Drift Error vs. Wind Type for the 1979-1981 Data. N is the number of observations, P is the probability, and df is the degrees of freedom for each test. The bins for wind type are indicated by an "X".

No Wind	Analysis	Predicted	χ^2	df	P	N
X	X	X	47.186	24	$.001 < P < .01$	667
	X	X	2.965	10	$.98 < P < .99$	436
X	X		30.819	12	$.001 < P < .01$	476
X		X	25.576	12	$.01 < P < .02$	422

TABLE 4-8. Statistical Comparison Between Wind and No Wind Cases for the NAVO File (24-hour predictions only, 1979-1981)

	Analysis and Predicted Winds	No Wind
Number of obs.	103	53
R-factor		
Median	3.27	3.00
Percentile (25th, 75th)	1.70, 4.30	2.00, 4.80
Range	8.41	10.60
Bearing difference[1]		
Median	-3.4	4.6
Percentile (25th, 75th)	-48.5, 56.7	-77.2, 64.0
Range	355.2	348.0
Relative Drift Error[2]		
Median	-1.04	-3.99
Percentile (25th, 75th)	-2.09, -0.11	-10.64, -2.04
Range	9.35	38.05

Notes: 1. Negative bearing difference indicates that the actual drift direction is to the right of the predicted drift.

2. Relative Drift Error = (Predicted-Actual)/Predicted.

4.6.3 Effect of Wind Type on 24-hour SARP Predictions Made With NAVO

In the preceding two sections it was established that, for both bearing and distance accuracy, there is no statistical performance difference between the analysis and predicted wind cases. For distance accuracy, there is a clear dependence of the results on whether or not wind (either analysis or predicted) generated current is included in the SARP drift computation. For bearing accuracy, such a dependence is suggested but the test results were not conclusive.

Although a dependence between the performance of predictions using wind and those made without winds has been established, which is the more accurate has not been considered. To determine the answer, the performance of the NAVO 24-hour predictions as a function of wind type was examined. The NAVO sea current file was chosen for this detailed comparison with wind type for two reasons. First, the SARP predictions for which the NAVO was the sole sea current used constitute the largest single data category. Second, the use of the NAVO file for SARP predictions in the study area means that the search target was not in the areas covered by FLDA, CORE or EDDY, all of which are dominant sea current files. As a result, the SARP predictions for the NAVO areas are most likely to be significantly affected by wind generated currents.

For the test, the analysis and predicted wind cases were combined and compared with the no wind case. The three measures of performance used were the R-factor which is the number of first search radii between predicted datum and interpolated buoy position, the bearing difference between predicted and actual direction of drift, and the relative drift error. For each measure of performance, the mean, the 25th and 75th percentiles (an indication of the spread of the data), and the entire data range were calculated. The results are shown in Table 4-8. Note that the range for R-factor is greater for the "no wind" case even though there are fewer observations, and there is a greater spread between the 25th and 75th percentiles for bearing difference. The use of predicted and analytical winds result in a considerably smaller relative drift error than by neglecting the wind-driven currents.

4.7 Prediction Time vs. R-factor

This analysis addresses the issue of whether or not the accuracy of the SARP drift predictions degraded as the prediction time increased. For this investigation the R-factor was used as the measure of effectiveness. In Section 4.5.3 it is shown that there is a correlation between prediction time and sea current file in the data; therefore, the contingency analysis must be done separately for each current file. CORE and EDDY lacked sufficient data for the analysis. All of the data (1979-1981) were used.

For NAVO, the three categories for prediction time were 24-hour, 48- and 72-hour, and 96-and 120-hour. The four categories for R-factor (R_f) were $0 \leq R_f \leq 2$, $2 < R_f \leq 4$, $4 < R_f \leq 7$, and $7 < R_f \leq 9$. The analysis yielded an $\chi^2 = 40.0121$ with 6 degrees of freedom for $P < .001$. The results for the FLDA file are shown in Table 4-9. In both cases, the null hypothesis, that prediction time and R-factor are independent, can be rejected at the .05 significance level. By comparing the observed values with the expected values in Table 4-9, a trend of larger R-factors for larger prediction times is evident.

TABLE 4-9. Prediction Time vs. R-factor for FLDA for the 1979-1981 Data. The observed and expected (in parenthesis) values are presented for the listed R-factor and Prediction time bins. P is the probability and df is the degrees of freedom.

		Prediction Time (hours)			
		2-24	48	72, 96, 120	Total
R-factor	0-4	53 (45.7)	6 (7.7)	0 (5.6)	59
	4.01-15	77 (84.3)	16 (14.3)	16 (10.4)	109
	Total	130	22	16	168

$\chi^2 = 11.076$
df = 2
$.001 < P < .01$

The nature of the dependence of R-factor on prediction time for the NAVO file can be seen in Table 4-10. R-factor in general increases with longer prediction time as indicated by the increase in the mean (3.27 to 6.50) and the percentiles. There is no such noticeable trend in the bearing difference. Although there is a significant increase in the median (-3.4 to 24.0), the data distribution, as indicated by the 25th and 75th percentiles, does not suggest an increasing trend. Finally, in the relative drift error, there is some evidence for an error that increases at longer prediction times (75th percentile), although the case is not as strong as for the R-factor.

Table 4-10 also suggests that the distance the buoys drifted was significantly and persistently underestimated when the NAVO file was used. This is demonstrated by the negative relative drift error values of both the median and 25th and 75th percentiles. It is important to recognize that a relative drift error of -1.0 is substantial because it means the search object drifted twice the predicted distance. On the other hand, there is no apparent systematic error in the bearing accuracy of the NAVO file; as indicated by the 25th and 75th percentiles, the bearing differences are distributed around zero.

TABLE 4-10. Statistical Summary of the Performance of NAVO With Wind (analysis and predicted winds combined) as a Function of Prediction Time. For each of three performance criteria the median value and the 25th and 75th percentile are presented.

Prediction Time	Number of Observations	R-factor Median	R-factor Percentiles 25th	R-factor Percentiles 75th	Bearing Difference (Predicted-Actual) Median	Bearing Difference Percentiles 25th	Bearing Difference Percentiles 75th	Relative Drift Error Median	Relative Drift Error Percentiles 25th	Relative Drift Error Percentiles 75th
24-hour	103	3.27	1.70	4.30	-3.40	-48.50	56.70	-1.038	-2.095	-0.106
48-hour	24	5.90	4.20	7.15	20.45	-70.40	56.05	-0.683	-3.321	0.066
72-hour	12	7.65	3.85	9.65	18.20	-53.05	109.50	-0.969	-2.972	-0.497
72-hour 96-hour 120-hour	33	6.50	4.60	7.90	24.00	-59.20	87.30	-1.725	-2.208	-0.576

4.8 Current Files

In the following subsections, the performance of each of the current files is addressed. Except for EDDY, the discussion is of a statistical nature based only on 24-hour predictions using predicted and/or analysis winds. The strengths and shortcomings of NAVO, FLDA, and CORE are addressed with regard to bearing accuracy, relative drift error, and effectivity. In 4.8.4, a narrative comparison of the actual and predicted movement of a buoy encountering an eddy, when EDDY was used, is given.

4.8.1 NAVO

Table 4-11 gives the statistics for NAVO. This file has a rather large standard deviation for bearing accuracy, but no systematic error. The file underestimates the net amount of drift approximately three quarters of the time. In half of the observations, the actual net drift was greater than twice the predicted net drift. However, the file is effective; datum is on the average a nautical mile closer than the last known position to the interpolated buoy position. The effectivity (E_f) is greater than zero at the 0.05 significance level.

NAVO is unusual in that it is the only file to have a meaningful correlation coefficient (0.80) between the actual net drift and the distance from datum to the interpolated buoy position. This observed correlation is consistent with the assumption that the further an object drifts, the larger the expected error in predicting its location. No such correlation exists between the predicted net drift and either the actual net drift or the distance from datum to the interpolated buoy position. It appears that the mechanisms causing the larger net drifts are not represented in the NAVO file (eddies, Gulf Stream meanders, etc.).

4.8.2 FLDA

Table 4-12 gives the statistics for FLDA. This file has systematic errors in speed and direction. The predicted direction of drift is to the left of the actual direction at a significance level of 0.05, and the systematic error is greater than 5 degrees at the 0.1 significance level.

The systematic error in predicting speed probably has the larger impact on prediction accuracy. The predicted drift is greater than twice the actual drift over half the time. The average actual drift is on the order of 20 to 25 nautical miles in 24 hours, while the average predicted drift is approximately 50 nautical miles.

As a result of these systematic errors, using the FLDA file is counterproductive in making a prediction at a 0.001 significance level. Three quarters of the time, the interpolated buoy position was closer to the last known position than it was to datum.

TABLE 4-11 Statistics for 24-Hour Predictions Using Wind (analysis and predicted winds combined) and NAVO. Based on 103 Observations.

Bearing Difference:	mean			3.0
	st. dev.			83.1
	95% confidence limits on mean			-13.2 to 19.3
Relative Drift Error[1]:				
25th percentile	40th percentile	Median	60th percentile	75th percentile
-2.09	-1.34	-1.04	-0.64	-0.11
Effectivity (E_f):	mean			1.09
	st. deviation			6.41
	95% confidence limits on mean			-0.16 to 2.34

Note: 1. Population is skewed to left so median and percentiles are better parameters than mean and standard deviation.

TABLE 4-12 Statistics for 24-Hour Predictions Using Wind (analysis and predicted winds combined) and FLDA. Based on 78 Observations.

Bearing Difference:	mean			-17.4
	st. dev.			81.6
	95% confidence limits on mean			-35.8 0.9
Relative Drift Error[1]:				
25th percentile	40th percentile	Median	60th percentile	75th percentile
0.29	0.50	0.53	0.59	0.67
Effectivity (E_f):	mean			-15.6
	st. dev			29.0
	95% confidence limits on mean			-22.2 -9.1

Note: 1. Population is skewed to left so median and percentiles are better parameters than mean and standard deviation.

4.8.3 CORE

Table 4-13 gives the statistics for CORE. Like FLDA, this file possesses systematic errors in direction and speed. The predicted direction of drift is to left of the actual; the systematic error is greater than 5 degrees at the 0.05 significance level.

CORE overestimates the net drift amount, but not nearly as much as FLDA. Half of the time, it overestimates the drift by approximately 20%.

CORE, unlike FLDA, is an effective file at the 0.1 significance level. The interpolated buoy position is closer to datum than the last known position in approximately 60% of the cases, and in half of the cases, over 15 miles closer.

TABLE 4-13 Statistics for 24-Hour Predictions Using Wind (analysis and predicted winds combined) and CORE. Based on 34 Observations.

Bearing Difference:	mean		-20.0	
	st. dev.		51.4	
	95% confidence limits on mean		-38.0	-2.1
Relative Drift Error[1]:				
25th percentile	40th percentile	Median	60th percentile	75th percentile
0.039	0.092	0.192	0.346	0.452
Effectivity(E_f):	mean		8.33	
	st. dev.		35.85	
	95% confidence limits		- 4.19	20.84

Note: 1. Population is skewed to left so median and percentiles are better parameters than mean standard deviation.

4.8.4 EDDY

During the three-year experiment there were very few cases in which the search target was identified as being in an eddy; in no case was EDDY the only file used for a SARP run. Because EDDY was so rarely utilized, it is not possible to calculate meaningful statistics on its performance. A single graphical example of the use of EDDY will, however, illustrate some of the file characteristics as well as the difficulties associated with using EDDY.

Buoy 2647 was slightly to the north of the estimated position of a cold core eddy centered at approximately at 28° 20' N and 77° 35'W (Figure 3-8) on 3 March 1980 (JD 63). The last known position (▲) and predicted target movement (X) for a 72-hour SARP run using predicted winds are shown in figure 4-1. Also shown are the interpolated buoy positions for the period of the SARP prediction. The X's and squares along the tracks indicate positions at 24-hour intervals. The approximate position of the eddy as it existed in EDDY is indicated by the dashed circle; the position of the CORE is also shown.

The SARP drift track indicates a southerly target movement (under the influence of vigorous north winds) for the first 24 hours of drift. At this juncture the target was predicted to have entered the eddy and commenced the characteristic cyclonic (counter-clockwise) motion associated with cold core eddies. The shaded area indicates the circle of radius R (first search radius) around the 72-hour datum.

The actual buoy movement was quite different from the predicted trajectory and the interpolated buoy position is well outside the search area. The buoy appears to have entered the eddy at the time of the LKP and commenced its movement to the west, albeit at a much slower rate than that predicted by SARP. The predicted speed of the target in the eddy was approximately 1.6 knots (82 cms^{-1}) while the actual speed was 0.6 knots (31 cms^{-1}). There are two possible explanations for this observed behavior; the eddy could have been north of its estimated position or considerably larger than its IR signature. During this time the sea surface was obscured by clouds and during such periods it is difficult to define the exact position or dimensions of an eddy. Estimating eddy positions based on previous positions and estimated movement is risky because frequently the eddy movements are erratic, particularly when they are in close proximity to, and interacting with the Gulf Stream (Richardson, 1980).

The preceding example illustrates several important points. First, a very good estimate of the location and size of an eddy, such as described above, can nevertheless, lead to erroneous SARP predictions. The exact boundaries of the eddy are of critical importance to the success of a prediction. Second, the present method of locating water mass boundaries (satellite IR imagery) is severely handicapped by cloudiness. It is also important to recognize that eddies do not always have recognizable surface temperature characteristics (Richardson, et al., 1979); thus not all eddies can be detected using IR imagery.

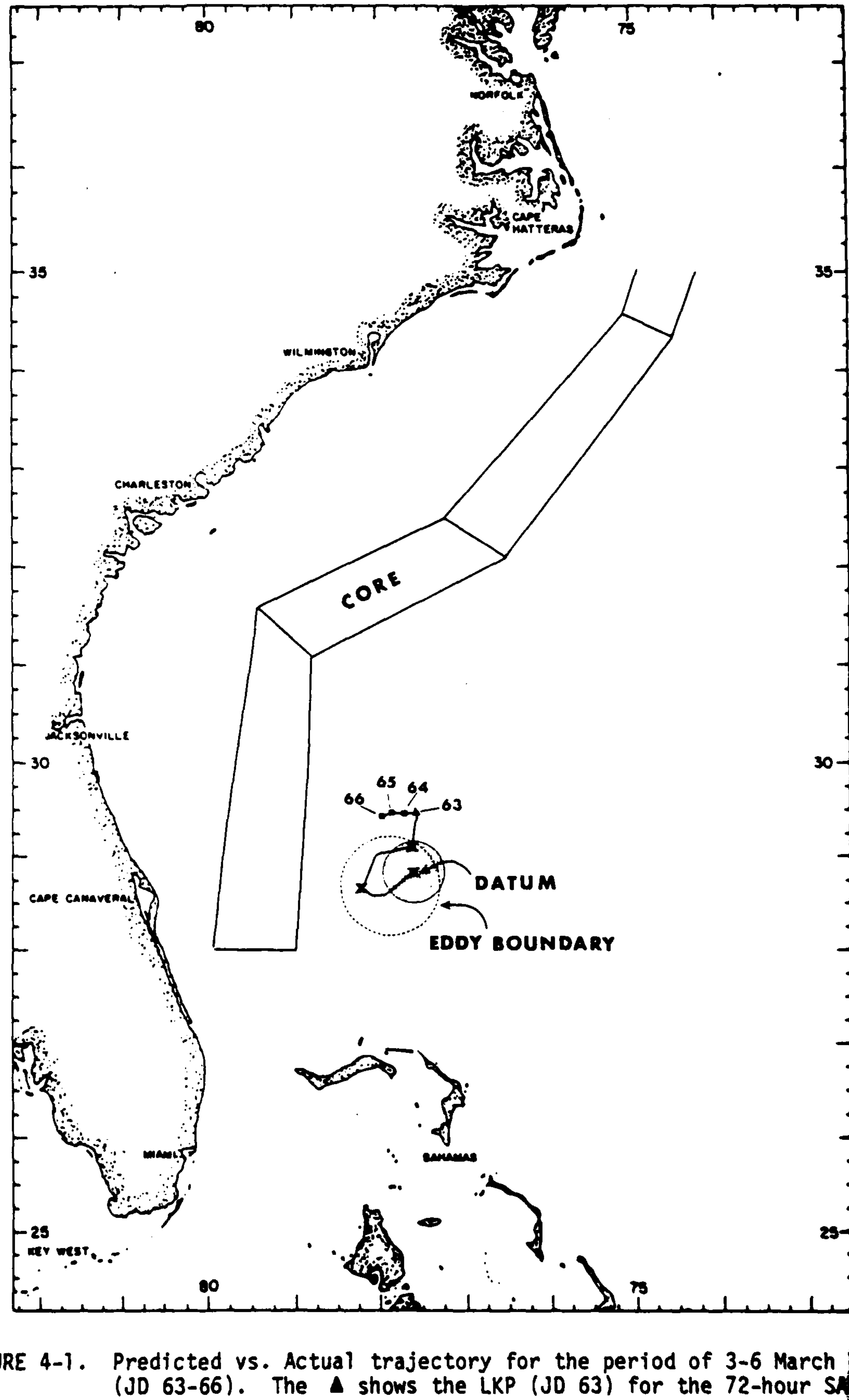


FIGURE 4-1. Predicted vs. Actual trajectory for the period of 3-6 March (JD 63-66). The ▲ shows the LKP (JD 63) for the 72-hour SA run. The darkened squares indicate the interpolated buoy positions for each date; the X's indicate the SARP-predicted positions.

4.9 Drift Error Factor

The final issue to be addressed is the accuracy of the drift error factor, E_d, a nondimensional quantity used to determine the uncertainty of a drift prediction. It is based on Equation 2-1 and 2-2 (repeated below for convenience), which is the expression for the probable error of position (E).

$$E = (D_e^2 + X^2 + Y^2)^{1/2} \qquad \text{(Eq.2-1)}$$

$$D_e = (E_d)\,(TD) \qquad \text{(Eq.2-2)}$$

where,

D_e = total drift error
TD = total predicted drift distance (nmi).

Throughout the entire SARP drift evaluation, an E_d of 1/8 was used in the computation of D_e. It is important to recognize that the value of E is used to compute the first search radius, and thus, the size of the search area is acutely sensitive to the value of E. Because both X and Y were held constant (3 nmi) during the experiment, the importance of E_d in the determination of the size of the search area is clear.

The proposed amendment to Chapter 8 of the SAR Manual changes the value of E_d to 0.3, more than doubling the contribution of D_e to Equation 2-1. To examine the effect that using $E_d = 0.3$ has on the experimental results, TD was computed using the first search radius from the SARP output and Equations 2-1, 2, 3. A new first search radius was then computed for $E_d = 0.3$; Table 4-14 presents the R- factor distributions for $E_d = 1/8$ and $E_d = 0.3$.

With the exception of the NAVO data, there is a dramatic difference between the R-factor (R_f) distributions. For the FLDA data and using $E_d = 0.3$, 42.5% of the cases were in the range $0 \le R_f \le 2$. This means that the search target was within a distance equivalent to 2 first search radii from the datum. Using $E_d = 1/8$ this occurred in only 12.5% of the cases. The newer value of E_d improves the results of the drift predictions made using the NAVO file but the change is not quite as dramatic.

TABLE 4-14. Distributions of R-factors (R_f) for Drift Error Factors (E_d) of 1/8 and 0.30.

Only SARP predictions using analysis and/or predicted winds, and prediction times of 24 hours or less were used. Under current files, the "ALL" is the total for the three individual files plus all file combinations. The format is

N obs Cell %
Cumulative %

"N obs" is the number of observations for the cell.

		R-factors (R_f)								
Current File	E_d	$0 \le R_f \le 1$	$1 < R_f \le 2$	$2 < R_f \le 3$	$3 < R_f \le 4$	$4 < R_f \le 5$	$5 < R_f \le 6$	$6 < R_f \le 7$	$7 < R_f$	Total Obs
NAVO	1/8	13 12.6 12.6	17 16.5 29.1	16 15.5 44.7	26 25.2 69.9	14 13.6 83.5	5 4.9 88.3	7 6.8 95.1	5 4.9 100.0	103
	0.30	14 13.6 13.6	21 20.4 34.0	26 25.2 59.2	22 21.4 80.6	6 5.8 86.4	10 9.7 96.1	2 1.9 98.1	2 1.9 100.0	
FLDA	1/8	3 3.8 3.8	7 8.8 12.5	5 6.2 18.8	17 21.2 40.0	13 16.2 56.2	8 10.0 66.2	7 8.8 75.0	20 25.0 100.0	80
	0.30	11 13.8 13.8	23 28.8 42.5	16 20.0 62.5	19 23.8 86.2	7 8.8 95.0	1 1.2 96.2	1 1.2 97.5	2 2.4 100.0	
CORE	1/8	3 8.8 8.8	10 29.4 38.2	1 2.9 41.2	5 14.7 55.9	3 8.8 64.7	3 8.8 73.5	3 8.8 82.4	6 17.6 100.0	34
	0.30	13 38.2 38.2	7 20.6 58.8	7 20.6 79.4	1 2.9 82.4	3 8.8 91.2	0 0.0 91.2	1 2.9 94.1	2 5.9 100.0	
ALL	1/8	22 8.8 8.8	38 15.1 23.9	26 10.4 34.3	49 19.5 53.8	37 14.7 68.5	24 9.6 78.1	19 7.6 85.7	36 14.3 100.0	251
	0.30	45 17.9 17.9	56 22.3 40.2	58 23.1 63.3	53 21.1 84.5	16 6.4 90.8	13 5.2 96.0	4 1.6 97.6	6 2.4 100.0	

The newer value of E_d is a significant improvement over the 1/8 value; however, the data in Table 14-4 suggest that E_d should be even larger. The first search radius is defined so that there is a better than 50% probability that the search target will be within the search area. Using the R-factor, this means that 50% of the cases should be in the range $0 \leq R_f \leq 1$. This fundamental criterion is not satisfied by the aggregated data (17.9%) nor by any of the individual data files.

Finally, the actual drift error factor (E_{ad})for each case was computed using the expression

$$E_{ad} = \frac{Dx}{TD}$$

where;

Dx = distance between datum and the interpolated buoy position.
TD = total predicted drift.

The median of the E_{ad} is an estimate of E_d based on the experimental data.

The median values of E_{ad} for each of the major current files and for various prediction times are presented in Table 4-15. The computed values are considerably higher than the proposed 0.3 drift error factor. The median value of the aggregated data is .96 which means that the drift error was approximately as large as the total predicted drift. It is also evident that E_{ad} is larger for the NAVO file than for either CORE or FLDA and that E_{ad} does not vary significantly with increasing prediction time.

TABLE 4-15. Computed Drift Error Factors (E_d).

Only those predictions using predicted and/or analytical winds were used. Values listed for individual files are for those files exclusively. The values listed under "ALL" are for all predictions regardless of the individual or combination of current files used. "ALL TIMES" is for prediction times up to and including 120 hours. The numbers of observations are given in parentheses.

Prediction Time	Current Files with Wind			
	NAVO	FLDA	CORE	ALL
24-hour	1.53 (102)	0.77 (78)	0.61 (34)	1.00 (247)
48-hour	1.41 (24)	--- (7)	--- (14)	0.93 (67)
72-hour	--- (12)	--- (2)	--- (7)	1.05 (38)
ALL TIMES	1.33 (159)	0.79 (108)	0.66 (45)	0.96 (421)

5.0 CONCLUSIONS AND SUGGESTIONS

5.1 Conclusions

The following conclusions are based on the results presented in Chapter 4:

5.1.1 Summary

o SARP drift predictions. The overall performance of the SARP drift predictions was poor. In only 6% of the 680 cases evaluated was the search target within the predicted search area. When only the 24-hour drift-interval is considered, the success increases slightly to 9.1%. The success for drift intervals of >24 hours was extremely poor (1.5%).

o Wind. The results of the SARP drift predictions are insensitive to whether predicted or analysis winds are used. However, the performance of the SARP drift predictions is clearly affected by whether or not the effect of wind is included in the computations. A detailed analysis of SARP predictions made with NAVO shows that if winds are neglected in the computations, the result is a larger relative drift error. It is important to reiterate that, because the leeway of the search target (buoy) is assumed to be zero for this study, wind enters into the SARP calculations only in the generation of wind-driven surface currents.

o Length of prediction. Most of the data point to the not too surprising conclusion that the performance of the SARP drift predictions degrades with increasing prediction time. The success analysis shows that for 24-hour predictions in 9.1% of the cases the target was within the search area while, for predictions of longer than 24 hours, the success ratio was 1.5%. The contingency analysis demonstrates that the performance of the drift prediction is related to the prediction time while further statistical analysis suggests that the performance degrades with increasing prediction time.

o Current files. The sea current files used in the SARP drift predictions contain some systematic errors which adversely affect the system performance.

-- NAVO underestimates the net drift approximately 75% of the time and in 50% of the cases the actual drift is twice the predicted drift. It is, nonetheless, an effective file because datum is consistently closer to the target position than the LKP.

-- FLDA has systematic errors in both speed and direction of the net drift. The drift is consistently over-estimated and, in approximately 50% of the cases, the predicted drift is twice that observed. The mean bearing error is to the left of the actual drift which, for the northward flowing Florida Current, implies that the targets were generally to the east of their predicted positions. The data show that FLDA is not an effective file because 75% of the time the target was closer to the LKP than to datum.

-- CORE also has systematic errors in both the speed and direction but they are not nearly as serious as those of FLDA. CORE overestimates the drift by approximately 20% in 50% of the cases. The mean bearing error is again to the left of the actual drift and, as with the FLDA file, that implies that the targets were generally to the east of the predicted positions. CORE is an effective file because the target position was closer to the datum than the LKP in approximately 60% of the cases.

o Drift error factor. The 1/8 value of E_d is unreasonably small to be of any assistance in estimating the drift error and $E_d = 0.3$, although an improvement, still underestimates the drift error associated with the present current files. The actual drift error, as determined from the present data, is approximately 1.0. This means that the error is nearly equal to the total predicted drift.

5.1.2 Discussion

The results of this study show that there are serious errors in the SARP drift predictions and that it is likely that the observed errors are due to the sea current files. Because of this conclusion, it is important to consider the possibility that the experimental methods contributed significantly to the observed errors. There are two possible contributors: first, the assumption that the buoys have zero leeway and second, the need to interpolate adjacent buoy positions for direct comparison with the predicted datum.

Assuming that the buoys have zero leeway is well supported by the experimental data; the drift predictions for the four drogued buoys were no more accurate than the undrogued buoys. For the 24-hour drift interval a typical drift error was in the range of 20-30 nmi. For a 20-30 kt wind, a leeway drift of approximately 10% of the local wind speed would be required to account for this observed error. This figure is unreasonably high for the buoy hulls used in the study; the actual leeway is probably less than 1%.

The interpolation required to arrive at a position to compare with the predicted datum is a source of error but again, it probably cannot account for errors on the order of 20-30 nmi. Most of the data were collected from the 1980 buoy releases and for each buoy there were 3-4 good fixes each day. As a result, the typical interpolation was over a 6-8 hour period and even for the vigorous surface current of the study area it is not likely that this interpolation would consistently result in 20-30 nmi errors. The interpolation errors were probably 5 nmi or less.

Errors of the magnitude documented in this study could be caused only by seriously deficient sea current files. This conclusion is particularly important recognizing the fact that a newer, more sophisticated SAR planning system (CASP) has recently replaced SARP. Although CASP is based on sound probability and statistics theory, the success of its predictions depends heavily on the quality of the input data. Among the sea current files available to CASP are NAVO and FLDA, two of the three current files tested in the present study. There is little reason to believe that a similar experiment conducted in the study area and using CASP would produce substantially different results. Indeed, one of the effective files (CORE) is not available to CASP in its present form. Although there were some evident problems with CORE, the file was effective and was based on a sound concept and modern technology (satellite IR imagery). Therefore, with the implementation of CASP and the concurrent closing of the Oceanographic Unit, the quality of the sea current files took a step backward. For a representation of the Gulf Stream, CASP will rely on the historical set and drift data of the NAVO file which has little recognition of the Gulf Stream complexities such as meanders and eddies which are so familiar to mariners.

Below are some final comments on the sea current files examined during this study.

1. NAVO. Because NAVO is based on historical set and drift data which contain, to an unknown extent, leeway and wind current, it does not exactly fit the SARP definition of a sea current fule. Periodically, the recommendation is made to use this file *without including the wind-driven current*. The present data show that, in the study area, the NAVO file is a slightly better performer when wind-driven current is added as is the case with all the other sea current files. Whether this is true in areas where the surface flow is driven primarily by persistent winds would have to be investigated.

2. FLDA. Predicting the movement of an object in the FLDA area is deceptively difficult, particularly with a time-invariant file. The Florida Current is known to have significant variability both on the seasonal time scale and on a much shorter (1-2 week) scale (Niiler and Richardson, 1973). Most of the data used to construct the FLDA file were collected by Richardson et al. (1969) during the months of May to July, a period of high Florida Current flow. The experiments described in this report were conducted during winter months (January - March), a period of relatively low flow. Typical surface currents in the summer are 0.5 to 1.0 kts higher than the winter values according to Niiler & Richardson. Although it is tempting to conclude that the seasonal variability explains the observed overestimation in the SARP drift predictions made using FLDA, the large short period variations are a serious complicating factor.

The directional errors in the predicted net drift are not particularly surprising because FLDA is time-invariant. This file has little recognition of eddies interacting with the Gulf Stream and protrusions of the Gulf Stream in the FLDA area. In numerous cases, drifters in the FLDA area showed dramatic eastward motion associated with features such as these. This is a possible explanation for the observation that, in the mean, the targets were found to the east of the predictions made using the FLDA file.

3. CORE. This file is the part of the GULF file for which sufficient data were collected to allow for meaningful analysis. As with the FLDA file, many of the targets moved to the east of their predicted positions which is consistent with the large variability associated with the eastern portion of the Gulf Stream. Often, the Gulf Stream interacts with cold core eddies which result in protrusions of the Stream to the east and southeast. Numerous buoy tracks show this behavior. At times the satellite IR data, from which CORE was generated, will recognize these events and the surface flow can be estimated. Many times, however, the IR data will miss the features due either to cloudiness or lack of a strong IR signature. During the months of January through March, winter cloudiness is a constant problem in the study area.

Regrettably, insufficient data were collected in 1981 to evaluate the effect of the GULF override option. As a result, the issue of whether CORE outperforms FLDA in the area of overlap cannot be addressed here.

The concept of the CORE file is sound and it was an effective file. With more sophisticated data processing techniques, it is likely that the accuracy of CORE could improve. It is unfortunate that CORE is not available to CASP.

The prospect of the continued use by CASP of NAVO and FLDA needs to be addressed. There are three possible courses of action. First, it is essential that the actual drift errors associated with using these files are recognized and the search area be increased accordingly. Neither E_d=1/8 nor E_d=0.3 adequately estimates the total drift error. Larger values of total drift error lead to larger search areas, which further drain search resources. Searching a small area is expedient but the goal is to locate the target.

The second possible course of action is a major effort to improve the quality of the sea current files. The Oceanographic Unit, before it was closed, was addressing this problem but presently there is no organized effort to improve the sea current files.

A third course of action is to develop a nowcasting system. This system could be designed so that on-scene units could provide some oceanographic data (such as surface currents) back into the control computer so that the CASP system could refine and update the first drift predictions.

5.2 Suggestions

The following are several suggestions for future work leading to improvements in SAR drift predictions.

o Rerun the CORE area SARP evaluations using CASP (with the NAVO file) to determine whether the results are significantly different.

o If necessary, modify CASP to accept the GULF file and re-institute the analysis of satellite IR data to support the GULF file.

o Investigate the feasibility of making FLDA a non-static file to allow, at a minimum, a seasonal cycle.

o Develop a real-time data collection technique for use during search to update the sea current files to reflect on-scene conditions.

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APPENDIX A

SUMMARY OF RELEASE DATA
1979

ID#	BUOY TYPE	RELEASE POSITION LATITUDE (DEG-MIN)	RELEASE POSITION LONGITUDE (DEG-MIN)	DROGUE	RELEASE DATE (JULIAN DA
0116	NOD	28-04.5N	79-29.7W	No	29 Jan 79 (29)
0120	NOD	28-05.8N	79-35.0W	No	29 Jan 79 (29)
0133	NOD	28-06.0N	79-53.0W	No	29 Jan 79 (29)
0151	NOD	28-04.0N	79-46.9W	No	29 Jan 79 (29)
0167[1]	NOD	28-06.4N	79-41.1W	No	29 Jan 79 (29)
0210[1]	NOD	28-06.4N	79-41.1W	No	29 Jan 79 (29)

NOTE: 1. Buoys #0167 and #0210 were released at the same location.

These buoys were released by USCGC EVERGREEN.

SUMMARY OF RELEASE DATA
1980

ID#	BUOY TYPE	RELEASE POSITION LATITUDE (DEG-MIN)	LONGITUDE (DEG-MIN)	DROGUE	RELEASE DATE (JULIAN DAY
2644[1]	TOD	28-00.2N	79-15.0W	Yes	8 Feb 80 (39)
2645	TOD	28-01.5N	79-27.7W	Yes	8 Feb 80 (39)
2646[1]	TOD	28-00.2N	79-14.9W	No	8 Feb 80 (39)
2647	TOD	28-00.5N	79-39.3W	Yes	8 Feb 80 (39)
2648[2]	TOD	28-00.7N	79-27.3W	Yes	8 Feb 80 (39)
2649[2,3]	TOD	28-00.6N	79-27-2W	No	8 Feb 80 (39)

NOTES: 1. Buoys #2644 and #2646 were released at approximately the same location.
2. Buoys #2648 and #2649 were released at approximately the same location.
3. Buoy #2649 had a Scripps (cylindrical) Hull.

These buoys were released by USCGC EVERGREEN.

SUMMARY OF RELEASE DATA
1981

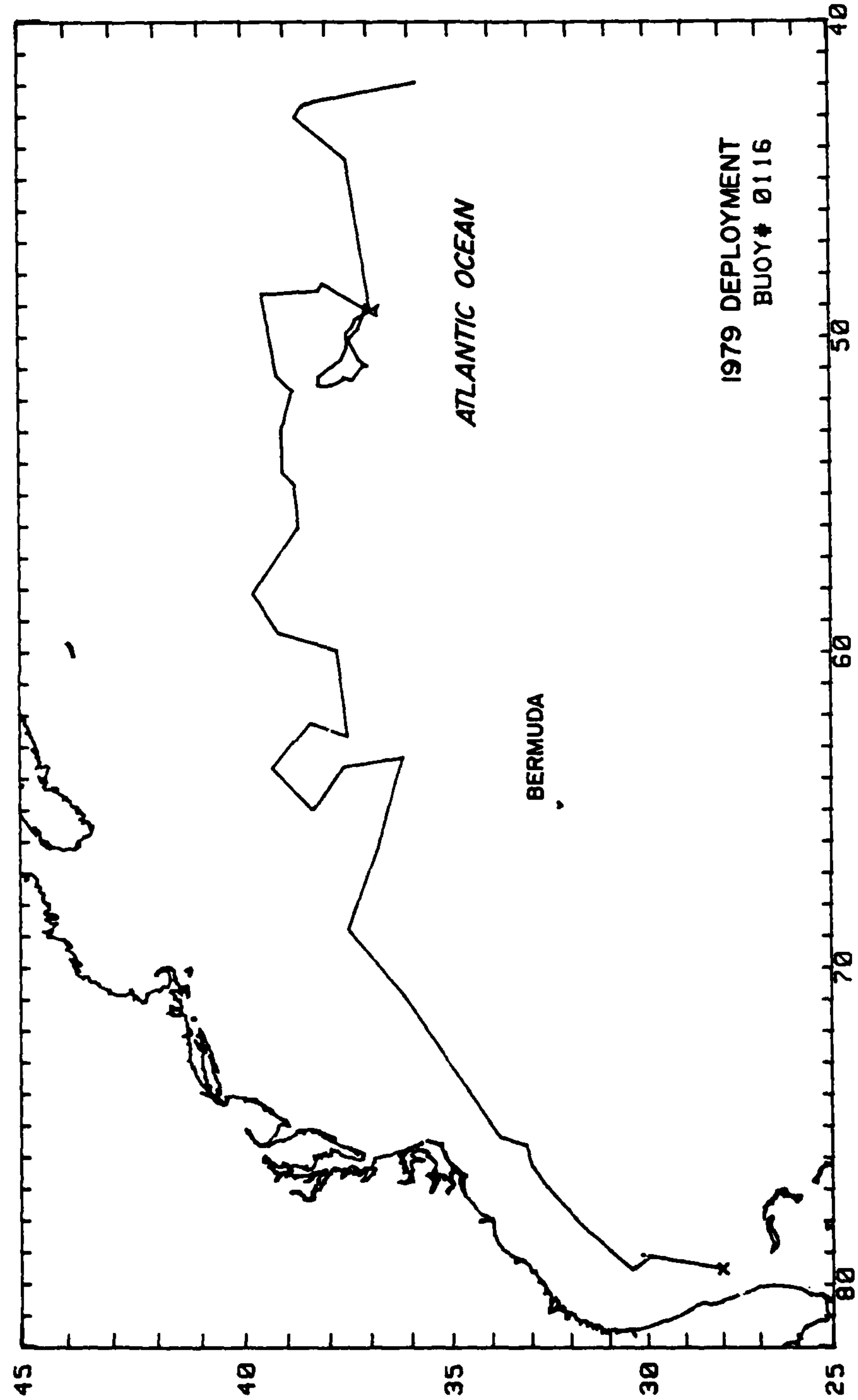
ID#	BUOY TYPE	RELEASE POSITION LATITUDE (DEG-MIN)	LONGITUDE (DEG-MIN)	DROGUE	RELEASE DATE (JULIAN DAY
0120[1]	NOD	28-00.3N	79-29.8W	No	3 Feb 81 (34)
2648[1]	TOD	28-00.3N	79-29.8W	Yes	3 Feb 81 (34)

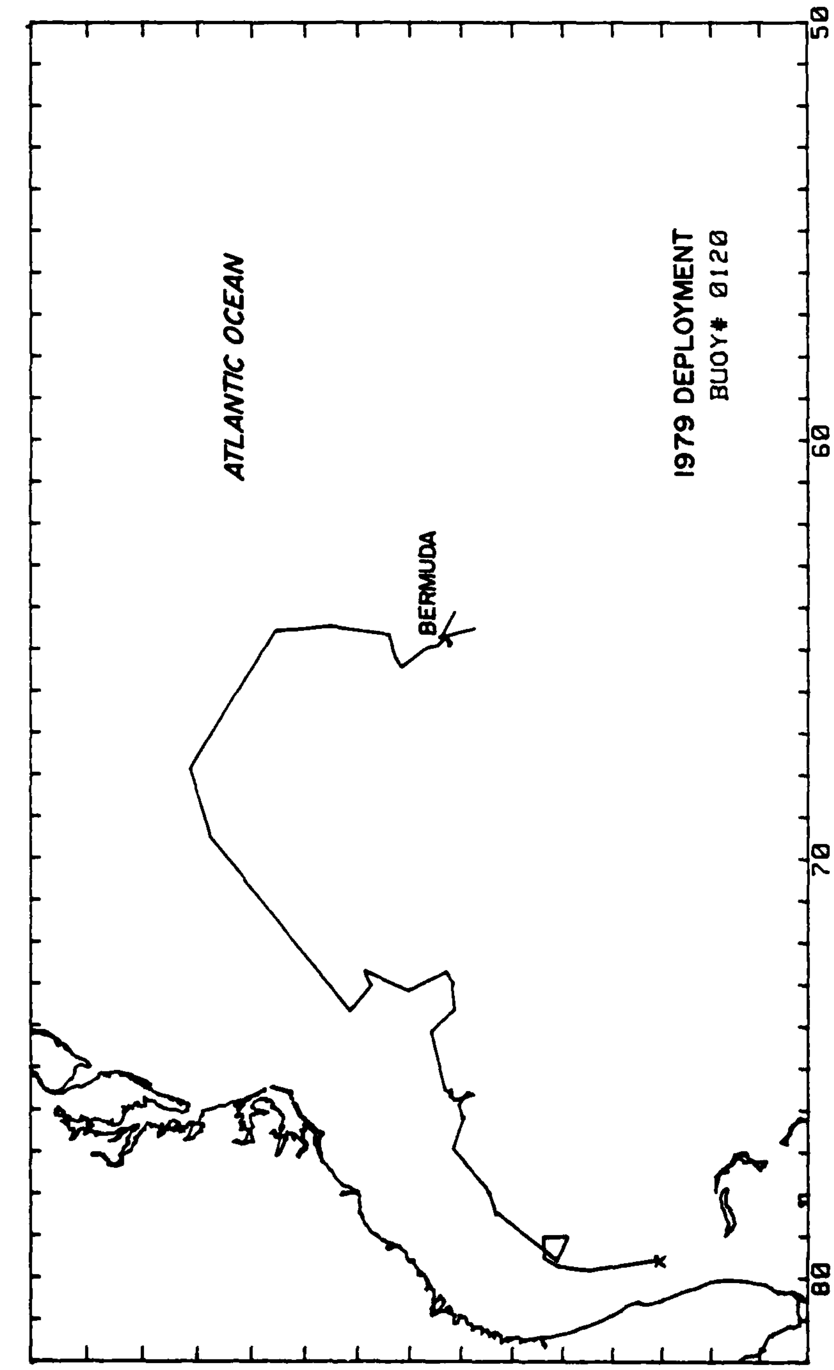
NOTE: 1. Buoys #0120 and #2648 were released at the same location.

These buoys were released by USCGC VIGOROUS.

APPENDIX B

Trajectories for the satellite-tracked buoys used in this study. The release data are presented in Appendix A.


ATLANTIC OCEAN
1979 DEPLOYMENT
BUOY# 0116
BERMUDA
45
40
35
30
25
80
70
60
50
40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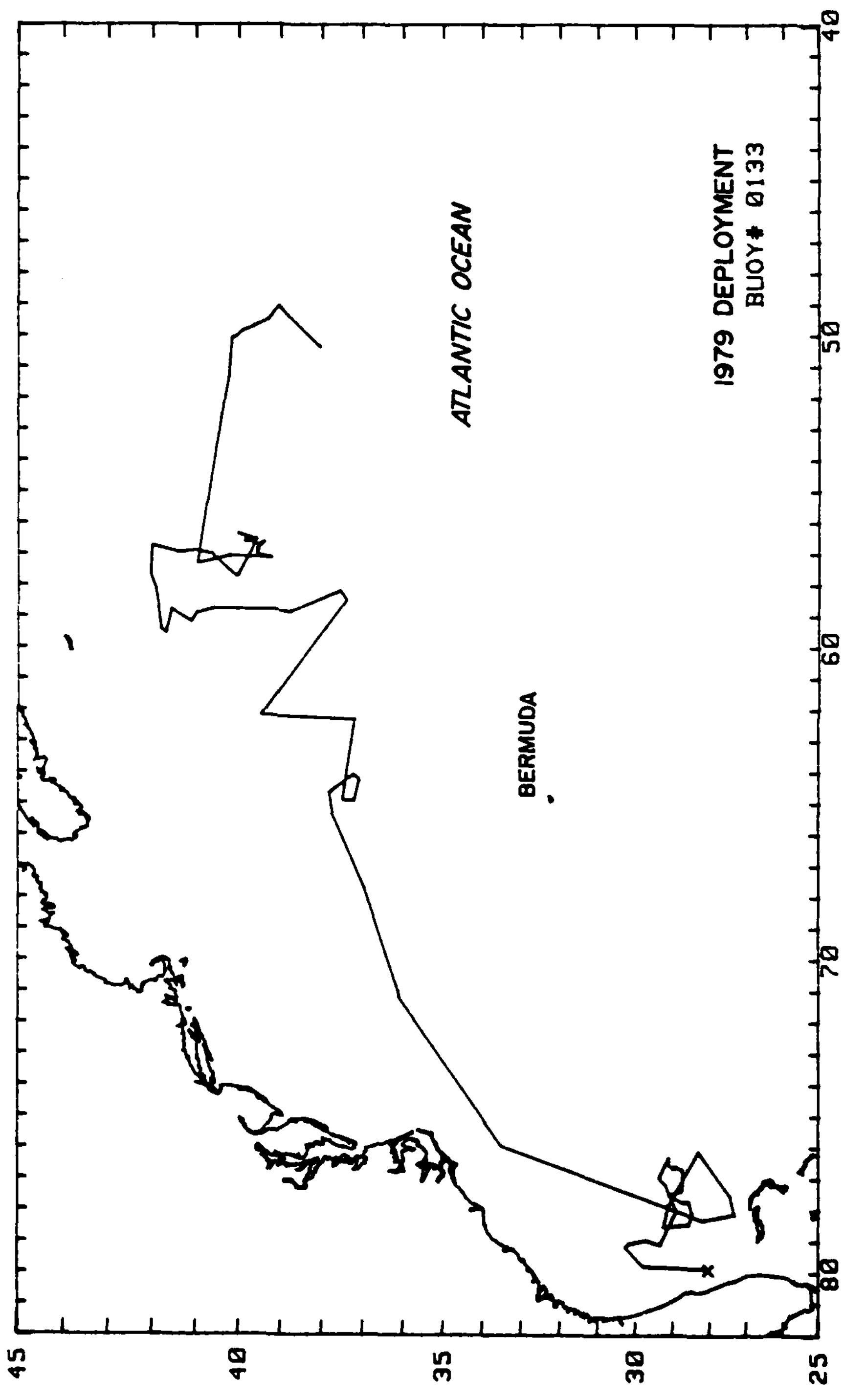
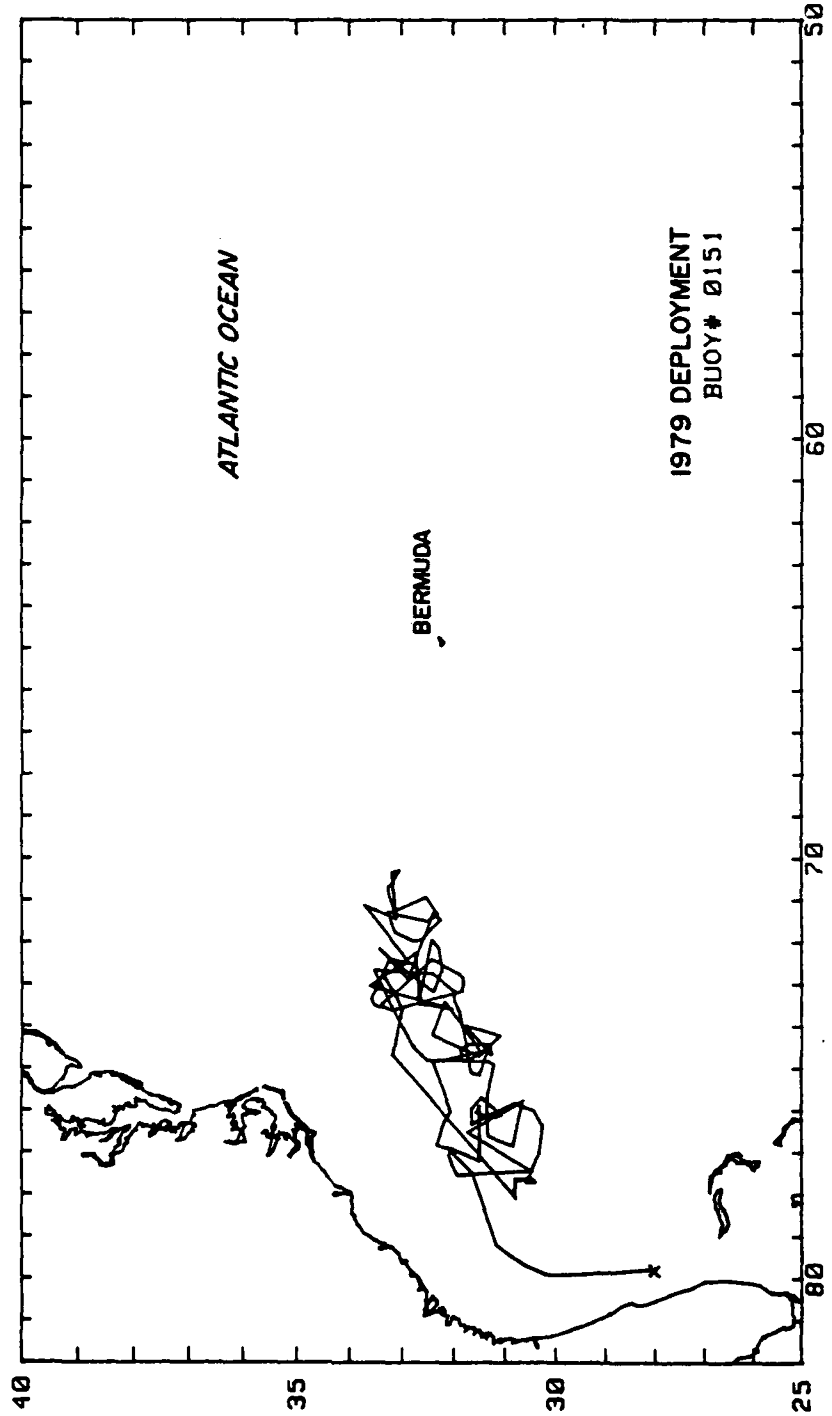
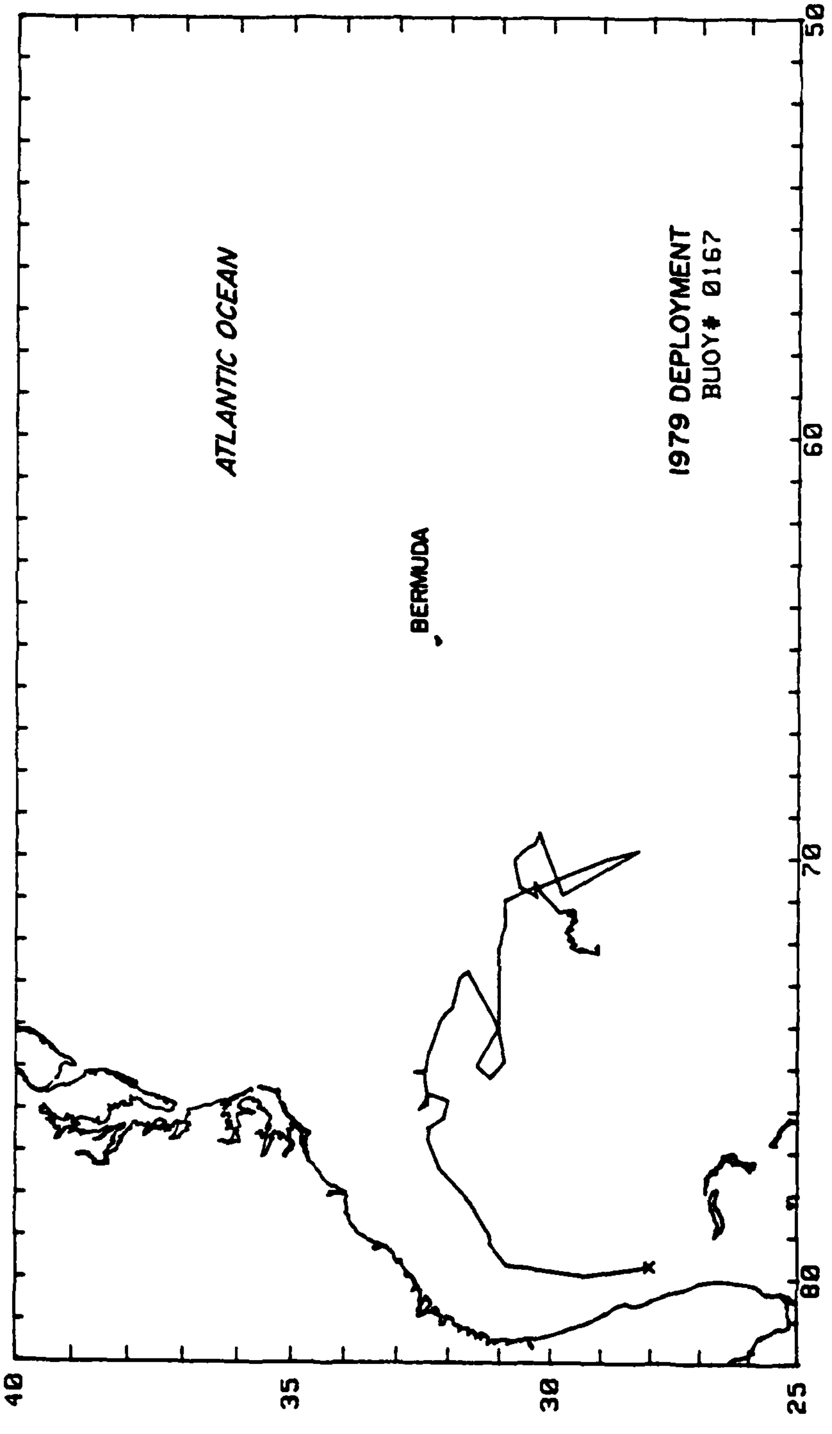
BERMUDA
1979 DEPLOYMENT
BUOY# 0120
40
35
30
25
50
60
70
80

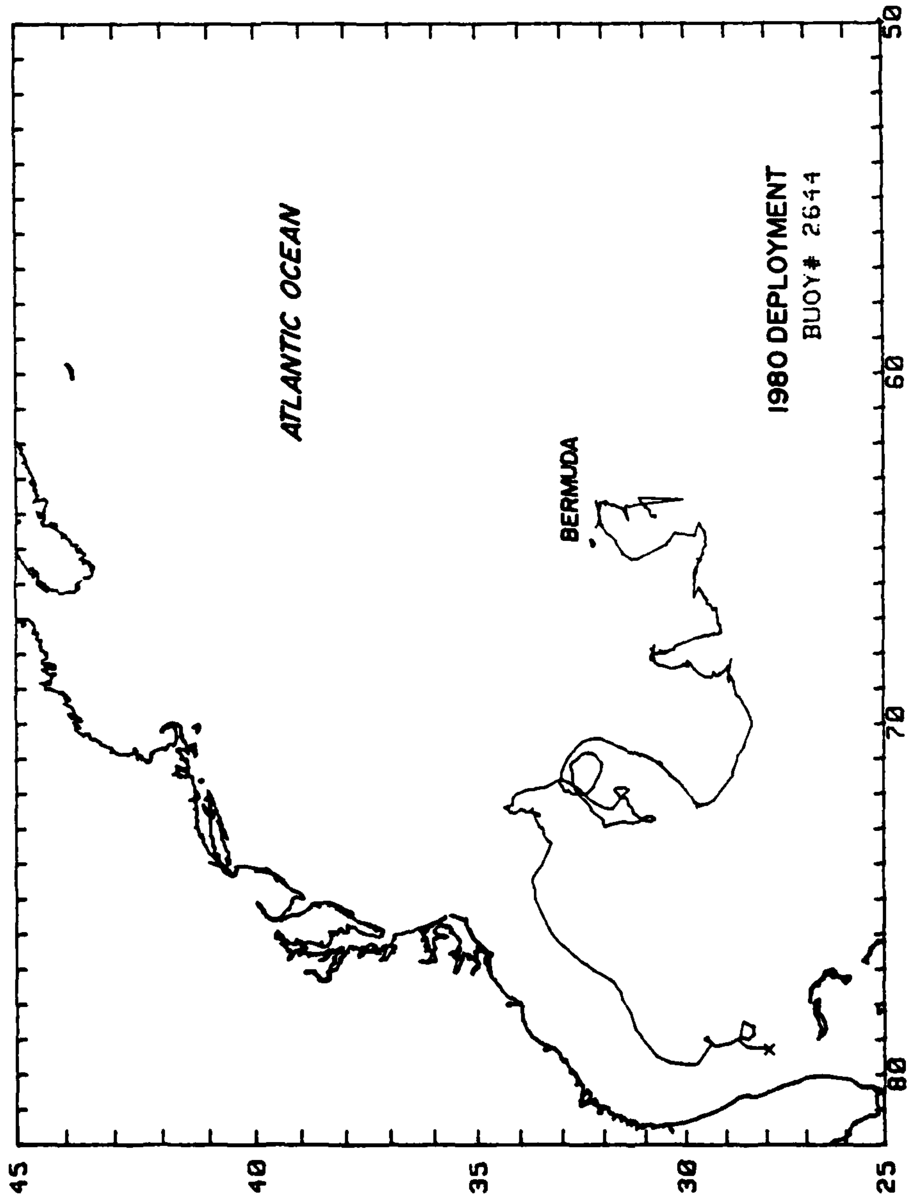


1979 DEPLOYMENT
BUOY# Ø133
ATLANTIC OCEAN
BERMUDA
45
40
35
3Ø
25
4Ø
5Ø
6Ø
7Ø
8Ø


ATLANTIC OCEAN
BERMUDA
1979 DEPLOYMENT
BUOY# Ø151
40
35
30
25
50
60
70
80



ATLANTIC OCEAN
BERMUDA
1979 DEPLOYMENT
BUOY# Ø167
40
35
30
25
50
60
70
80



ATLANTIC OCEAN
BERMUDA
1980 DEPLOYMENT
BUOY# 2644
45
40
35
30
25
80
70
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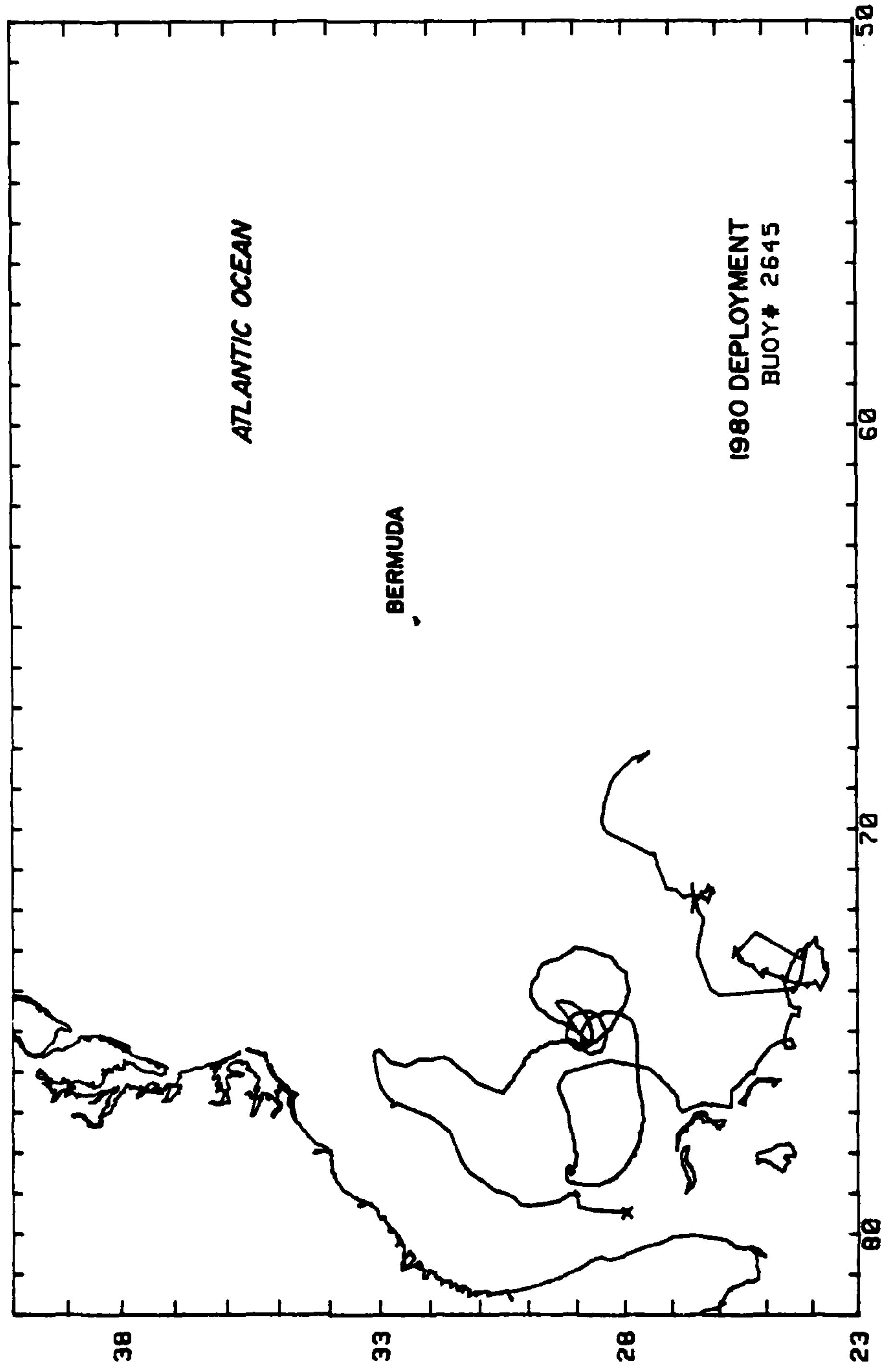
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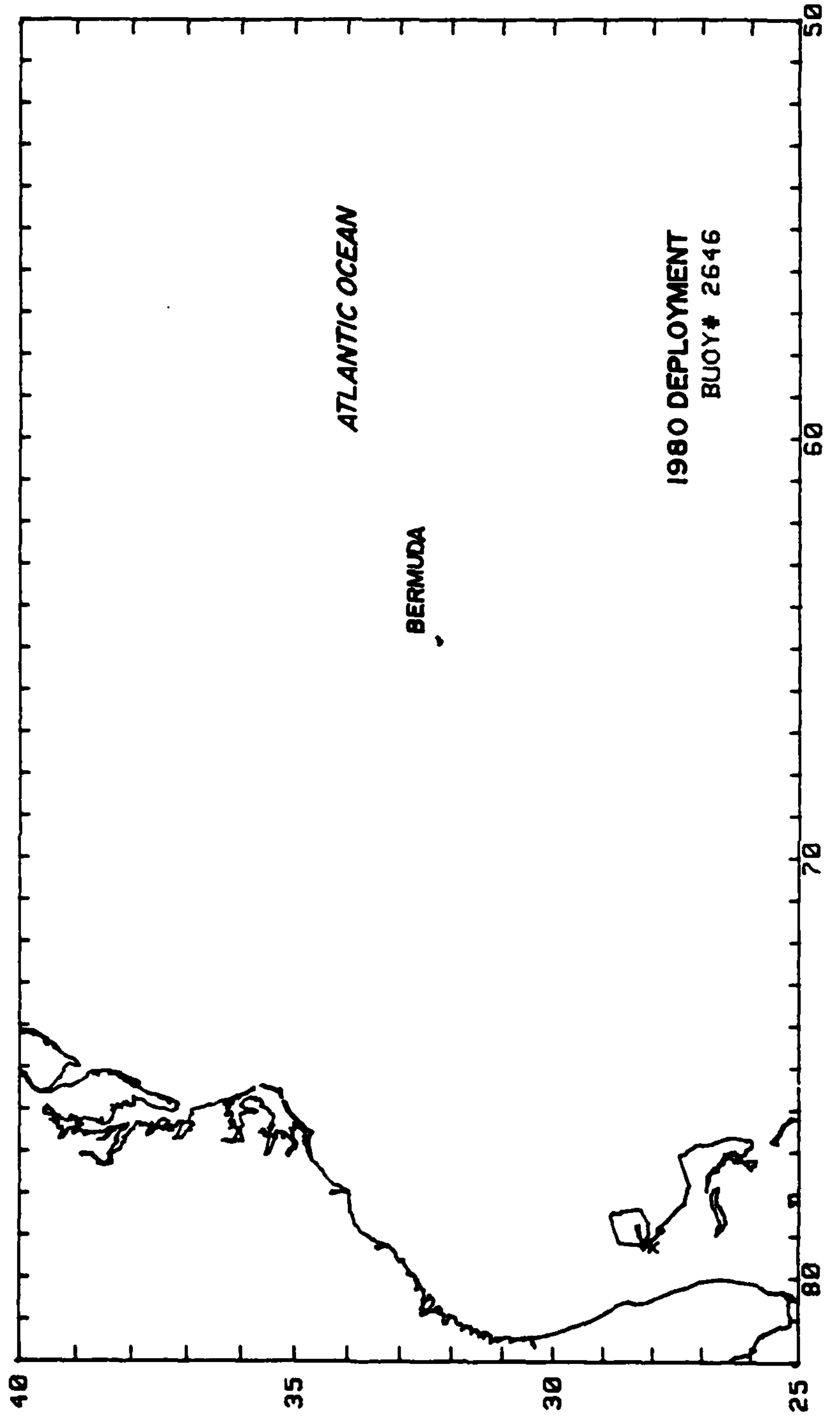
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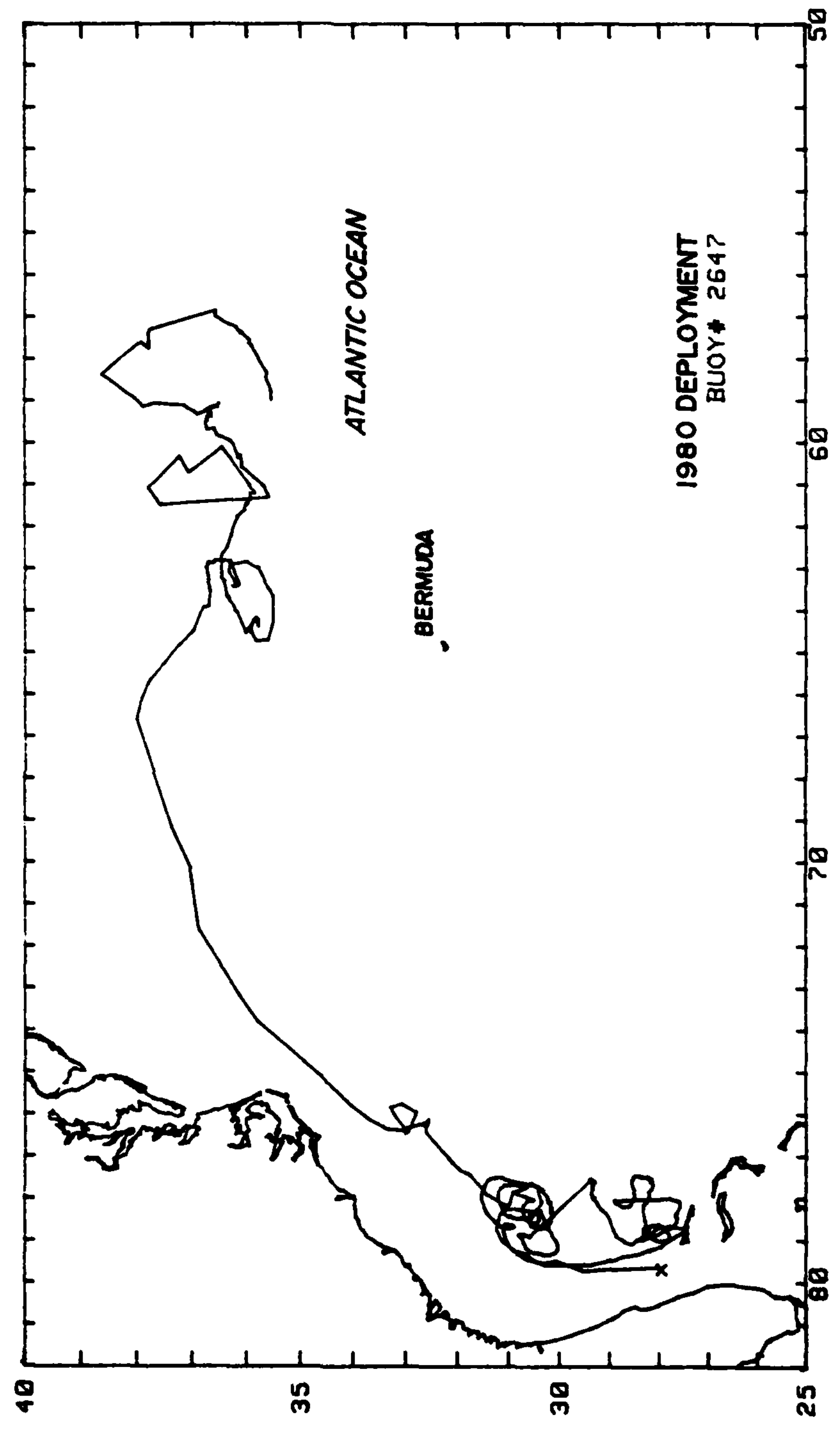
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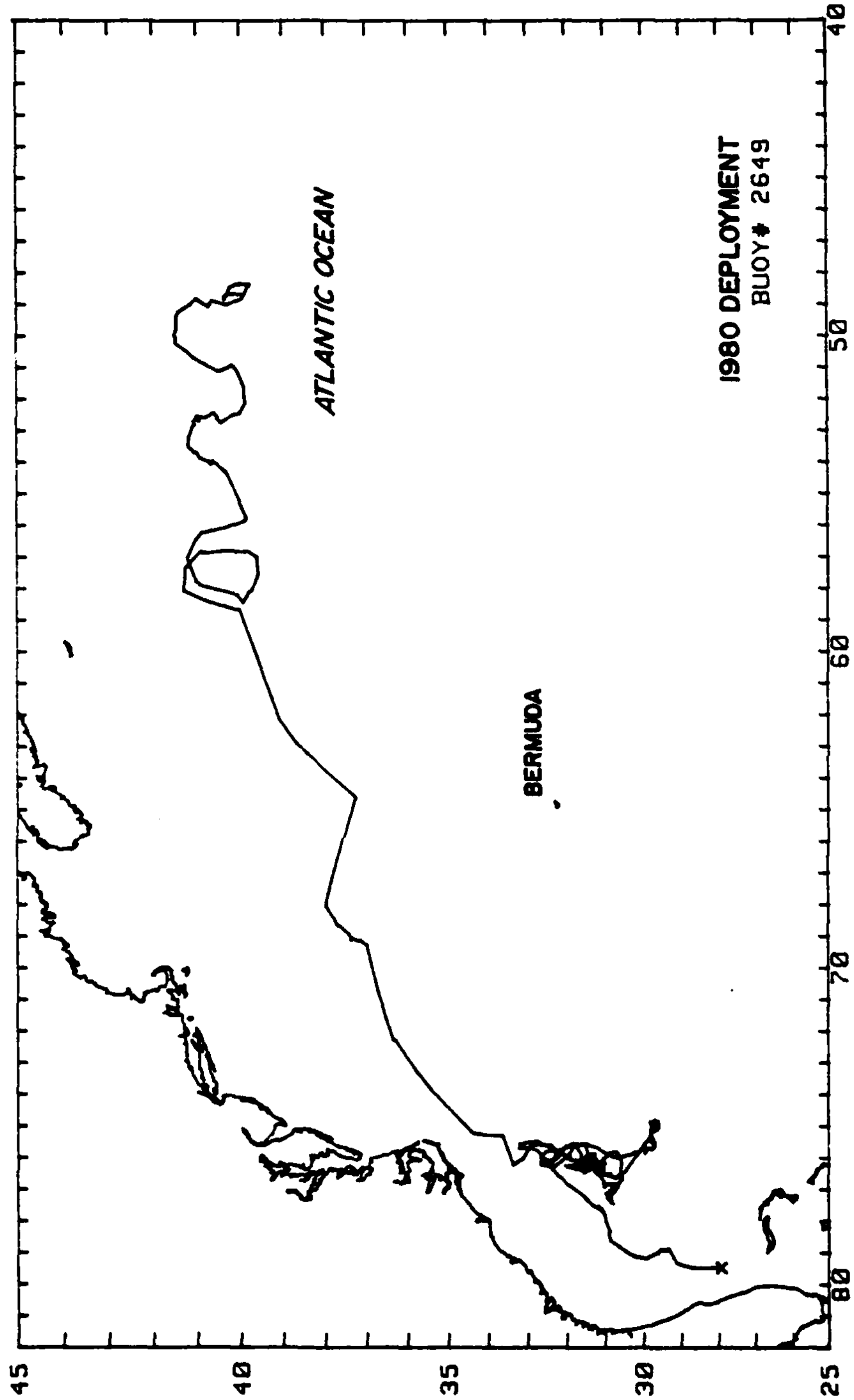
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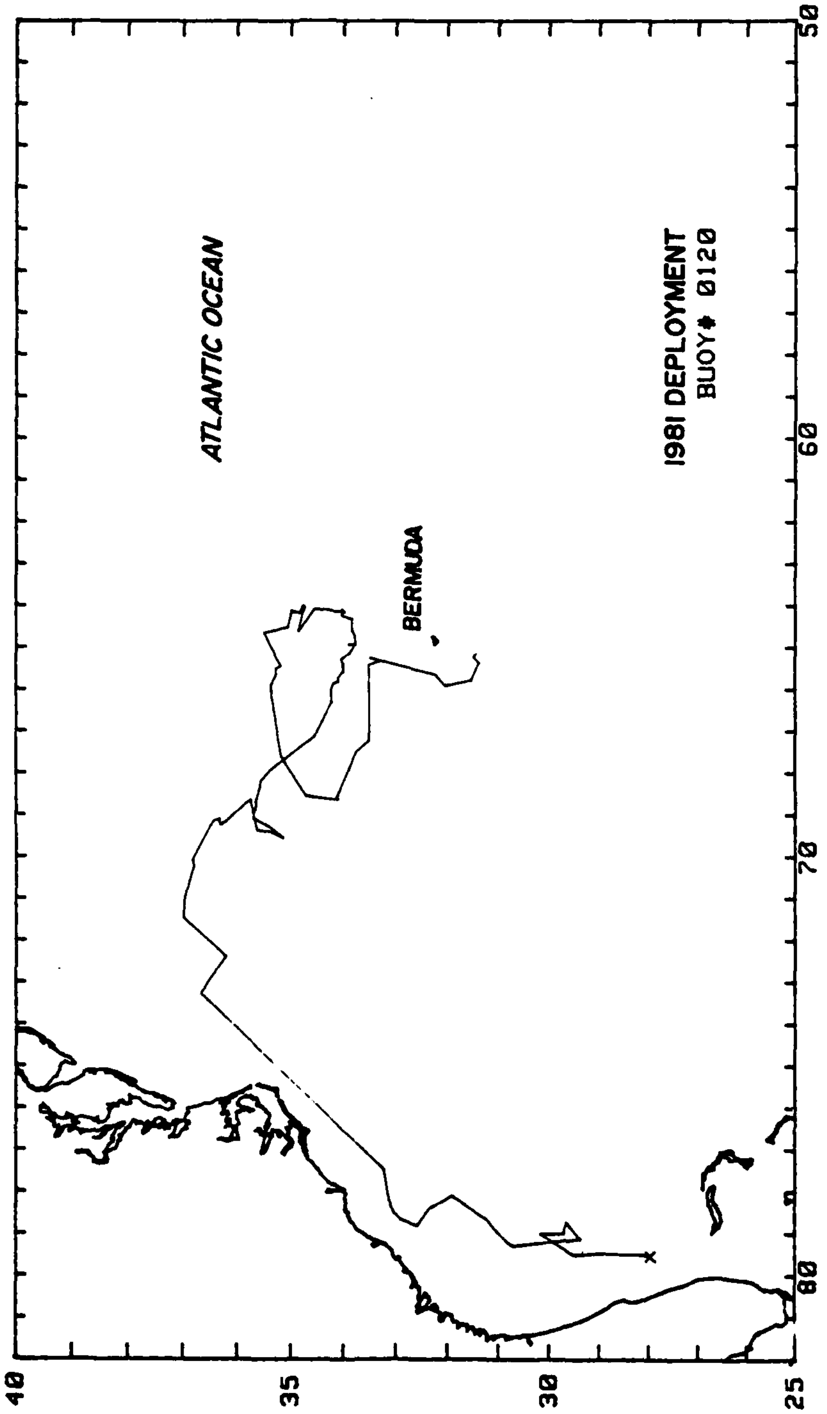
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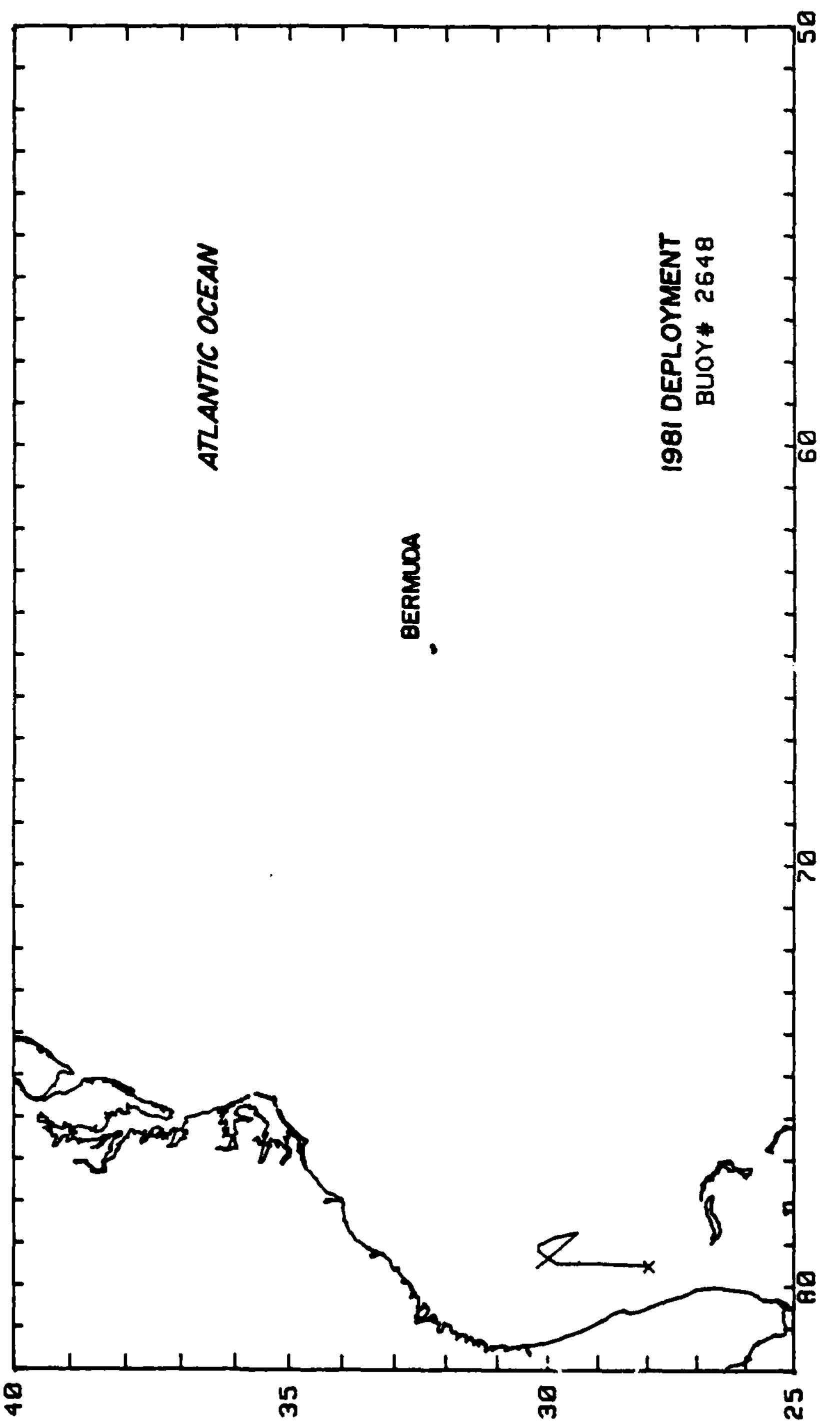

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